EVALUATION OF TECHNOLOGY FOR THE TREATMENT OF WASTE SLUDGE AND SOLIDS CONTAMINATED WITH SALT, METALS, AND HYDROCARBONS

Phase I Report to:

Canadian Petroleum Association

and

Conservation and Protection

Environment Canada

December 1989

CANADIAN PETROLEUM ASSOCIATION

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DISCLAIMER

This report has been prepared for the purpose of identifying those solids' treatment/disposal technologies that warrant further evaluation through bench-scale, pilot, or field demonstration trials.

Environment Canada and the Canadian Petroleum Association and its representatives accept no responsibility whatsoever for the actual performance of the treatment technologies described herein. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

SUMMARY

A number of oil companies have identified that although existing waste treatment/disposal methods used by the industry are adequate for some of the wastes considered in this study, they are either not appropriate or economically feasible when these materials contain fine-particle-sized solids and a wide range of contaminants such as oil, salt, and heavy metals. The Canadian Petroleum Association (CPA), with the support of Environment Canada, has embarked upon a study to identify treatment technologies capable of treating these hydrocarbon-contaminated solids and sludges. Phase I of the study is a global assessment of existing and emerging treatment technologies capable of handling wastes containing a wide range of contaminants and a significant portion of fine particles within the current and anticipated provincial and federal regulatory framework. Although the principal focus of Phase I is on emerging and developing high-technology-based processes, the report also idenifies existing low technology treatment/disposal options. These options may be suitable either to treat certain waste streams considered within the scope of this report or to be used in combination with high technology processes using a multi-process treatment train concept.

The types of waste considered in this study are generated in both conventional and heavy oil production operations and include storage tank bottom sludge, waste holding pond/pit sludge, emergency storage pit sludge, flare pit sludge, treater and skim tank interface pads, field tank sands, free water knockout and treater desand sludges, slop oil/sludges, ecology pit mixture, and spill debris. These wastes exhibit wide ranges of composition, including variable amounts of oil, water, solids, heavy metals, and salt. As a significant portion of these wastes has an average particle size of less than or equal to 60 microns, the technical steering committee decided to limit the scope of this assessment to treatment technologies with high potential for treating waste sludges and solids of finer particle size composition.

Federal, provincial, and U.S. waste management legislation that affects petroleum production wastes was reviewed. Both Canada and

the U.S. are continuously developing, upgrading, and amending their environmental protection acts and associated regulations, such as TDGA, CEPA, and RCRA, to improve the environment. As a result, it is anticipated that industries, including oil production, will be required to meet more stringent environmental regulations and improve on current waste handling, treatment, and disposal practices. In addition, the study would address one of the ERCB's current policy initiatives encouraging the "development of technologies to treat oily waste (in co-operation with the industry)".

Current practices include roadspreading, offsite disposal (landfarming, land treatment, landfill), waste oil reclaimers, and on-site storage in ponds/pits. However, these methods are becoming more and more difficult to implement for finer oily waste sludges and solids contaminated with heavy metals and/or salt. Without the development of new treatment technologies and processes capable of treating and disposing of these wastes, the industry will be severely hampered to meet new environmental control requirements.

The Phase I study investigated 32 treatment processes applicable to the types of oilfield wastes targeted for this demonstration program. These processes can be organized into six general treatment technology categories:

1. Solvent extraction
2. Aqueous extraction/leaching
3. Thermal treatment
4. Biodegradation treatment
5. In situ treatment
6. Other treatment/disposal methods
   (including land application methods of disposal)

After preliminary screening, 16 processes were further evaluated in detail, using criteria established through discussions with the technical steering committee for both commercial-scale and smaller individual-company-based applications.

For the small-scale local plant scenario, three of the top four rated processes (BP Oil, B.E.S.T., CF Systems) are solvent-

extraction-based technologies, while the fourth (U.S. EPA Soil Washer) is an aqueous extraction/leaching technology. For the large commercial-scale plant scenario, the same four processes (B.E.S.T., BP Oil, CF Systems, U.S. EPA Soil Washer) ranked in the top five. The fifth-ranked process is the Taciuk Processor which is a thermal treatment technology. It is apparent that thermal treatment, and in particular the Taciuk Processor, becomes more attractive at the commercial-scale facility where a larger volume of waste material is treated.

All of the top-rated emerging processes generate a residual wastewater and/or solid waste stream which will ultimately require additional treatment or disposal. Existing disposal/treatment methods can most likely be used for final residue disposal. This would have to be verified in future work planned for this overall waste management study.

The Phase I assessment has shown that emerging high technology processes will be required to handle the entire range of wastes contaminated with oil, salt, and heavy metals and with a significant fraction of fine material of less than 60 microns. Certain classes of generic treatment technologies such as solvent extraction and aqueous leaching/extraction are likely candidates for future consideration. Vendor-supplied solvent extraction processes such as B.E.S.T., BP Oil, and CF Systems have potential application for treatment of wastes described in Section 8. Aqueous leaching/extraction technology may also be applicable in treating these wastes and within this generic technology class, the U.S. EPA Soil Washer is a good example of the type of process which may be adaptable.

The next phase of this study will include the following:

1. An initial scope-focusing/criteria-setting phase to gather additional information regarding the characteristics of the various wastes and to develop waste treatment criteria/strategies, taking into consideration priority of wastes and corresponding low and high technology solutions

2. Detailed evaluation/assessment of the most applicable technology/process options, including bench/laboratory-scale testing
3. Demonstration of selected technology/process systems on a field pilot-scale level

It is recommended that the next phase of this project proceed based on a staged approach with at least two stages. Stage one would be a refinement of waste characterization data/information and detailed assessment and costing, and stage two would be the testing (laboratory bench-scale or field pilot-scale) of selected technologies.

The product of the next phase will be a comprehensive report presenting sufficient engineering and cost detail to enable participating member companies of CPA to determine the viability of the treatment process(es) and the scale of commercial or individual treatment facilities most suitable to their needs.

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1. INTRODUCTION

In auditing the waste disposal practices of its production facilities, the petroleum industry has identified that significant volumes of hydrocarbon-contaminated soils, sediments, and sludges are being produced. These wastes, in addition to hydrocarbon contamination, often contain various combinations of heavy metal and salt contaminants. The sources of these wastes are varied and include tank bottom sludges, wastewater holding pond sludges, in-field treater wastes, separator wastes, waste oil storage pond sediments, combined hydrocarbon and brine spilled cleanup material, and numerous other small sources originating from oil production operations. At the present time, much of this material in Alberta is located in the bottom of waste oil reclaimer ponds, old flare pits, oilfield-produced water ponds, and some petroleum industry storage facilities.

A number of oil producing companies have identified that existing treatment and disposal methods for hydrocarbon-contaminated solids and sludges are not suitable nor economically achievable when these materials are combined with heavy metals and/or salt contamination. Due to the lack of current treatment options, significant volumes of this type of waste are accumulating at a rapid rate.

Several organizations are actively promoting processes for the treatment of these types of waste. Many of them require answers to serious questions regarding operability, performance, and environmental acceptability.

Waste solids and sludges contaminated with hydrocarbons, salts and metals are a significant problem that the upstream petroleum industry cannot continue to overlook in light of increasing public and government concern over waste management issues. Furthermore, a significant hydrocarbon resource could be reclaimed from these wastes as an intermediate step to their treatment and disposal.

The Canadian Petroleum Association (CPA), with the support of Environment Canada, has embarked upon a study to identify treatment technologies capable of treating these hydrocarbon-contaminated solids. Phase I includes a survey and evaluation of existing and developing

processes and recommended technologies to be further evaluated in subsequent phases of this study. Although the principal focus of this study is on emerging high technology processes, the report also identifies existing low technology treatment/disposal options which may be suitable either to treat certain waste streams considered within the scope of this report or to be used in combination with high technology processes using a multi-process treatment train concept. This report summarizes the results of the Phase I study.

2. OBJECTIVES AND METHODOLOGY

The overall objective of the Phase I study was to identify, review, and assess the applicability of technologies capable of treating and disposing of various hydrocarbon-, metal-, and/or salt-contaminated solids and sludges generated by oil producers. Technologies would be suitable for implementation in either a large, regional, central plant or a small, local plant scenario. The specific objectives of the Phase I study are outlined below:

1. Conduct a literature and technology review to identify possible treatment and disposal options; identify economics (purchasing and operational) and assess applicability to Western Canada field and climatic conditions. This review included both existing low-technology-based processes and developing high-technology-based treatment options.
2. Collect field data, canvas oil companies, and complete a literature search to identify ranges of contaminants, including hydrocarbons, salts, and other organic pollutants (priority pollutants) likely to influence treatment and disposal efficiencies.
3. Review and identify the Canadian regulatory framework to identify treatment efficiencies, effluent and treated material requirements, and accepted residual solids concentrations for materials identified above.
4. Through arrangements with the Environmental Research Advisory Committee (ERAC) of CPA, liaise with appropriate Federal and Provincial government regulatory agencies.
5. Prepare a report identifying the technologies reviewed, and recommend those to be tested further.

To achieve the above objectives, a series of tasks were completed in the following areas:

1. Waste Characterization - Information relating to the physical and chemical characteristics of the waste was

collected by researching existing literature, distributing a questionnaire to participating oil companies, and visiting various sites. This information is presented in Section 3 of this report.

2. Environmental Regulations and Guidelines - The challenge in evaluating waste treatment technology for future use is not only in evaluating process technology, but in reviewing current and estimating future regulatory environmental requirements. This task was accomplished by reviewing relevant Canadian and U.S. legislation and regulations and by having discussions with government officials regarding waste management practices. This information is presented in Section 4.
3. Current Practice - Once the waste characteristics and environmental regulations governing the management of these wastes are defined, it is appropriate to describe and discuss the current waste management practices. This information was obtained through the consultant's inhouse experience as well as through discussions with representatives of participating oil companies, and site visits. Section 5 summarizes the results of this task.
4. Technology/Process Summary - Both existing low-technology-based treatment processes and emerging high-technology-based options were identified and evaluated. Section 6 presents six general categories of treatment technologies. Each has advantages and disadvantages. Section 7 presents a comparison of 32 treatment processes identified under the six general categories.
5. Assessment of Treatment Processes - The assessment of treatment processes was conducted in two steps. In step one, the 32 processes identified were reduced to 16 by assessing each with two preliminary screening criteria.

In step two, the 16 remaining processes were evaluated against 10 detailed evaluation criteria. The shortlist of technologies included both low-technology- and high-technology-based options. Screening and evaluation criteria were developed by CH2M HILL in conjunction with CPA and Environment Canada. The results of the assessment are presented in Section 8.

6. Study Summary and Recommendations - The findings of the study are summarized in Section 9. Recommendations for subsequent phases of the study are presented in Section 10.

3. WASTE CHARACTERISTICS

This section summarizes the waste types and their characteristics that formed the basis of this study. The data presented have been derived from the following sources:

1. Existing literature/reports
2. Responses to questionnaires received from operators
3. Information acquired during field visits
4. Information acquired during personal interviews with oil company staff

The documents reviewed following the literature search are listed in the bibliography section. A questionnaire (a copy of which is included in Appendix A) was distributed to 25 companies in 1988 November, requesting information such as estimated quantity and composition, location, current disposal practice, and disposal/reclamation technologies tried or evaluated for the various types of wastes. Twelve companies responded and returned questionnaires and of these 12 responses, two companies stated that no data were available. Meetings were held with two of the companies that had responded with data in their Calgary offices to further clarify and/or discuss the information. Information regarding waste volumes was obtained from a report prepared by Wotherspoon and Associates for CPA, 1989 January, entitled "Petroleum Industry Waste Management Strategy, Phase II, Draft Report". CH2M HILL's project team members also visited four sites in Alberta and Saskatchewan to review current waste handling/treatment/storage procedures and disposal methods, and generally discuss waste management issues with field operations staff. Relevant waste characterization data received are attached in Appendix A.

Table A.1, Appendix A, is a summary of the waste characterization data in Appendix A. The summary lists the waste types generated and their associated characteristics. Oil, water and solids content, pH, and particle size range are important parameters for evaluating and selecting suitable treatment processes. Heavy metals such as chromium and lead are important because of their toxicity and mobility in the environment.

Petroleum products also contain significant amounts of nickel and vanadium. Inorganic constituents such as calcium, magnesium, sodium, and choride are important criteria for evaluating corrosion and soil application potential.

From Table A.1, the wastes considered in this study exhibited the following range of characteristics:

1. Oil: varies from low of 4 to 6 percent to high of 50+ percent.
2. Water: varies from low of 4 percent to high of 70 percent.
3. Solids: varies from low of 10 percent to high of 85+ percent.
4. pH: varies from low of 4.8 percent to high of 12.5 percent.
5. Particle size: ranges from very fine material of 2 microns to coarse sand of 2-mm diameter with a significant portion of wastes having an average size of less than or equal to 60 microns.
6. Heavy metals: present in varying amounts.
7. Salts: present in varying amounts, being primarily calcium, magnesium, and sodium chlorides.

Wastes such as waste holding pond/pit oily sludge and flare pit sludge contain very high levels of oil, heavy metals, and salt and also contain a significant amount of fine materials (silty clay).

Such wastes would clearly be a problem with current waste treatment technology based on simple gravity separation processes and would not be suitable for land disposal options such as roadspreading and landfarming due to high levels of heavy metals and salts.

Current low technology waste treatment options would still be suitable for some of these wastes which do not contain high levels of salt and/or heavy metals contamination.

The following paragraphs briefly describe the various waste types addressed in this study.

3.1 STORAGE TANK BOTTOM SLUDGE

Sales grade crude oil may contain small quantities of sand and sludges (primarily waxes and asphaltenes) which will settle out in storage tanks. These must be removed when the tank is serviced, generally once every two or three years or during plant turnaround.

3.2 WASTE HOLDING POND/PIT SLUDGE

Waste holding ponds are earthen ponds located typically at field batteries and waste reclaimers' plant sites that collect a wide range of production wastes (they may include spill cleanup material) over many years of operation. Generally, the pond content can be classified into four layers of material: liquids, oily sludge, oily solids, and pond bottom earthen material. This study addresses disposal/treatment of oily sludges, oily solids, and pond bottom material only. Pond/pit liquids are not within the scope of this study.

The oily sludge is usually a black, gel-like material with a solids concentration of 43-64 percent by weight. Oily solids vary considerably in texture and composition and may contain anything from garbage to plant roots. Oily solids contain less water than oily sludge and have a solids concentration of 78-85 percent by weight. Pond bottom material is highly site-specific. It may consist of native silty clay backfill material or wind-blown debris.

3.3 EMERGENCY STORAGE PIT SLUDGE

For some older batteries, emergency storage pits have been used to catch the overflow from crude oil storage tanks. Free oil collected in these pits is normally reclaimed with vacuum trucks. A layer of oily sludge is often left behind.

3.4 FLARE PIT SLUDGE

Flare pits were used at older batteries to burn off various hydrocarbon wastes. This is no longer practised but a great number of these pits still exist in Alberta and Saskatchewan.

3.5 TREATER AND SKIM TANK INTERFACE PADS

Interface pads are hydrocarbon emulsions that do not meet sale oil specifications and often contain high clay concentrations.

3.6 FIELD TANK SANDS

Field tanks are sometimes employed at or near individual production wells. Over time, sand and soil particles in the production fluid settle to the tank bottom and are cleaned out periodically. Particle size distribution ranges widely from field to field. For example, data suggest that the sands produced from the Wabasca field are fine, silty sand with 43 percent of the particles less than 5.5 microns. In comparison, the sands produced in the Lindbergh area can be classified as medium to fine sand with 15 percent of the particles less than 70 microns.

3.7 FREE WATER KNOCKOUT (FWKO) AND TREATER DESAND SLUDGES

In heavy oil production, sand and sludges are routinely desanded from FWKO and treater vessels, and collected in desand pits. The desand pits are periodically cleaned out by transferring the pit material to ecology pits.

3.8 SLOP OIL/SLUDGES

Slop oil/sludges are sand-bearing liquids or sludges which usually contain an oil-water emulsion. The emulsion prevents separation of the oil by a conventional treater. These wastes are usually collected and held temporarily in tanks or pits.

3.9 ECOLOGY PIT MIXTURE

The ecology pit mixture is a composite of the above wastes. The ecology pits are central holding facilities that must be periodically emptied to permit space for wastes from ongoing operations. The mixture makeup varies widely from site to site. Segregation is normally practised to separate cleaned sand from oily materials or sludges.

3.10 SPILL DEBRIS

Spill debris is usually soil that has been contaminated with oil from an accidental spill. Sometimes, clean soil is added to spilled oil to aid in the cleanup. Agricultural hay, straw, or a synthetic material (e.g., Canweb) are also used as absorbents.

Spill debris is normally collected in a central holding pad (sometimes in drums), from which it is periodically removed for disposal. In some instances, it is also stored in ecology pits.

3.11 VOLUME OF WASTE MATERIAL

For heavy oil production, field tank sand and the ecology pit mixture make up the major portion of waste material at a typical facility. For conventional oil production, storage tank bottom sludge is likely to be the highest contributor of waste material annually. However, the various ponds and pits commonly found in southern Alberta and Saskatchewan that have been accumulating sludges and solids over a period of 20 to 30 years could be a major contributor of waste material if they were required to be cleaned up.

In an oilfield waste survey commissioned by CPA's Environmental Planning and Management Committee (Wotherspoon, 1989), the following annual volumes of generation were estimated:

1. Heavy oil production field tank sand - 219 000 m^3/year
2. Tank bottom sludge - 3850 m^3/year
3. Flare pit sludge - 350 m^3/year
4. Oil-contaminated debris and soil - 23 860 m^3/year

The above quantities are considered best estimates only of annual waste volume. No comprehensive information is available to estimate exact waste volumes.

3.12 SUMMARY

The scope of this study is limited to the types of waste solids and sludges described earlier. Wastes of similar characteristics associated with tar sands operation and gas processing are not included in this study. In addition, the data received from participating oil

companies indicate that the total waste volume consists of a significant amount of fine (silty clay) materials. The project technical steering committee decided to focus the current study on the treatment and disposal of this finer-particle-sized waste material. Additional studies on treatment options specifically for heavy oil produced sand and gas plant sludges and solids are either in progress or planned for the near future.

4. ENVIRONMENTAL REGULATIONS AND GUIDELINES

This section provides an overview of the federal and provincial legislation governing waste management in the petroleum industry. No attempt has been made to include all of the environmental statutes or to explain in any detail the ramifications of those discussed. A comprehensive list of acts, regulations, and guidelines that were assembled and reviewed is presented in the bibliography section. For specific information, the appropriate acts and regulations should be consulted.

4.1 FEDERAL LEGISLATION

The federal governing body for waste management is Environment Canada. Its primary focus is the international and interprovincial movement of hazardous waste as well as the treatment and disposal of hazardous wastes on federal land. Enforcement is through the Transportation of Dangerous Goods Act (TDGA) which is administered by Transport Canada. TDGA and its associated regulations are intended to provide national uniformity through safety standards applied to all activities related to the transportation of dangerous goods and hazardous wastes. The regulations provide for cradle-to-grave control of hazardous wastes by way of a manifest reporting system to track movements of hazardous wastes from generation to ultimate disposal.

TDGA uses a system which divides dangerous goods into classes and divisions based on established hazard criteria. There are nine different hazard classes, as follows:

Class 1 - Explosives
Class 2 - Gases
Class 3 - Flammable liquids
Class 4 - Flammable solids, substances liable to spontaneous combustion, and substances that on contact with water emit flammable gases
Class 5 - Oxidizing substances and organic peroxides
Class 6 - Poisonous substances and infectious substances
Class 7 - Radioactive materials

Class 8 - Corrosive substances

Class 9 - Miscellaneous dangerous goods

Schedule II, List II of the TDG Regulations is a comprehensive list of specific and generic groups of dangerous goods and hazardous wastes. Any waste material that is listed in Schedule II, List II or has the hazardous properties described by the criteria under any of the above nine classes is a hazardous waste.

Amendments passed include: reporting, reciprocity with the United States, PCB transport, placarding, waste definition and classification, financial security, empty drums, safety and prenotification. The TDG Regulations were amended in 1989 June to include a list of hazardous substances to be determined by the leachate extraction test. These additional criteria (for wastes only) were added to Class 9.3 of List II, Schedule II. These added criteria are presented in Table B.1, Appendix B. Comparing Table B.1 and the characteristics of wastes addressed in this study, some of the constituents such as chromium and lead are at or above the limits listed for these elements in Table B.1.

The new Canadian Environmental Protection Act (CEPA) was proclaimed in 1988 June. The section of CEPA most relevant to this study is Part II - Toxic Substances. The Act provides for a comprehensive regulatory scheme to control toxic substances at each stage of the life cycle from development and manufacture through transport, distribution, use and storage, and finally to their ultimate safe disposal as wastes. CEPA provides the federal government with comprehensive power to manage toxic substances. This power includes:

1. Substance regulations
2. Priority Substance List of suspected toxic compounds
3. Mandatory reporting
4. Export and import controls
5. Power to order recalls and cleanups
6. New inspection and enforcement powers
7. Significant potential fines for cases of non-compliance

Currently, there are nine substances regulated under CEPA. These are:

1. Chlorobiphenyls that have the molecular formula $C_{12}H_{10-n}Cl_n$ in which "n" is greater than 2

2. Dodecachloropentacyclo [5.3.0.$0^{2,6}$.$0^{3,9}$.$0^{4,8}$] decane

3. Polybrominated Biphenyls that have the molecular formula $C_{12}H_{10-n}Br_n$ in which "n" is greater than 2

4. Chlorofluorocarbon: totally halogenated chlorofluorocarbons that have the molecular formula $C_nCl_xF_{(2n+2-x)}$

5. Polychlorinated Terphenyls that have a molecular formula $C_{18}H_{14-n}Cl_n$ in which "n" is greater than 2

6. Asbestos
7. Lead
8. Mercury
9. Vinyl Chloride

Substances that are not on the list of toxic substances and for which control options are being developed are also not on the Priority Substances List (PSL). These substances include carbon dioxide, halons, oxides of nitrogen, oxides of sulphur, volatile organic compounds (including transportation fuels), and releases of chlorinated phenols resulting from wood protection and preservation practices. Following the preparation of these control options, the Ministers will consider proposing regulations for these substances.

Subsection 12(1) of CEPA states: "The Ministers shall compile and may amend from time to time a list known as the Priority Substances List (PSL), and the List shall specify substances in respect of which the Ministers are satisfied priority should be given in assessing whether they are toxic or capable of becoming toxic".

In 1989 February, the Minister of Environment published a list of 44 priority substances. All substances on this list must be assessed within 5 years as to whether or not they should be considered toxic under CEPA and a candidate for regulation. The substances on the PSL are listed below.

Group 1:	Arsenic and its compounds
	Benzene
	Effluents from pulp mills using bleaching
	Hexachlorobenzene
	Methyl tertiary-butyl ether
	Polychlorinated dibenzodioxins
	Polychlorinated dibenzofurans
	Polycyclic aromatic hydrocarbons
	Waste crankcase oils
Group 2:	Cadmium and its compounds
	Chlorinated wastewater effluents
	Chlorobenzene
	Chromium and its compounds
	Cresosote-impregnated waste materials
	Dibutyl phthalate
	1,2-Dichlorobenzene
	1,4-Dichlorobenzene
	1,2-Dichloroethane
	Dichloromethane
	Di-n-octyl phthalate
	bis(2-Ethylhexyl) phthalate
	Inorganic fluorides
	Nickel and its compounds
	Pentachlorobenzene
	Styrene
	Tetrachlorobenzenes
	1,1,2,2-Tetrachloroethane
	Tetrachloroethylene
	Toluene
	Trichlorobenzenes
	1,1,1-Trichloroethane
	Trichloroethylene
	Xylenes
Group 3:	Aniline
	Benzidine

Chlorinated paraffin waxes
bis(2-Chloroethyl) ether
bis(Chloromethyl) ether
Chloromethyl methyl ether
3,3-Dichlorobenzidine
3,5-Dimethylaniline
Methyl methacrylate
Mineral fibres
Organotin compounds (non-pesticidal uses)

Some of the substances on the PSL are constituents in the wastes considered in this study (e.g., volatile organic compounds such as trichloroethylene, chlorobenzene, toluene, and benzene and metals such as cadmium and chromium) and are potentially substances to be regulated under CEPA. Therefore, there is a good possibility that the handling, treatment, and disposal practices for oilfield solid wastes will have to be altered and upgraded in the future.

4.2 ALBERTA LEGISLATION

In Alberta, the Energy Resources Conservation Board (ERCB) administers the Oil and Gas Conservation Act. It regulates the handling and disposal of oilfield wastes. In addition, the Clean Air Act applies if there are gaseous emissions, and the Clean Water Act governs the release of liquids to surface waters. The last two Acts are administered by Alberta Environment.

ERCB's approach to waste management is:

1. ERCB approves oily waste treatment facilities.
   - Inspects, monitors, and enforces environmental policies
2. ERCB approves design and location of disposal wells.
   - Inspects and monitors the operation of wells
3. ERCB approves disposal of oilfield waste.
   - Frequent liaison with Alberta Environment and other government departments is required because oilfield waste and hazardous waste are not distinctly separate in all cases.

ERCB's recent presentation at the Western Enviro-Agricultural Laboratory Association (WEALA) Conference in 1989 May outlined its current policy initiatives on oily waste. These are:

1. Encouragement of volume reduction and recycling
2. Elimination of disposal to unsecure landfills
3. Development of central processors
4. Elimination of routine disposal of oily waste on roadways
5. Development of technologies to treat oily waste (in cooperation with the industry)
6. Investigation into toxicity and ultimate fate of oilfield waste materials
7. Encouragement of treatment and possible incineration as opposed to land disposal options
8. Development of analytical protocols
9. Development of QA/QC programs
10. Revisiting incineration (with Alberta Environment and CPA)

4.2.1 The Oil and Gas Conservation Act

ERCB is responsible for administrating the Oil and Gas Conservation Act. ERCB, with approval of the Minister of the Environment, may make regulations prescribing the measures to be taken to control pollution.

Section 8.01 states that no oil shall be stored in pits. Section 8.16 defines waste material as water, rubbish, debris, drilling fluids, oil, oily waste, sand tailings, or other products from a well, oil sands operation, tank, or other production installation. The operator of a battery shall:

1. Ensure that waste material is contained at all times.
2. Dispose of all waste material in such a manner that no soil, surface water, or underground source of potable water is polluted.
3. Ensure that waste material does not create a safety hazard or nuisance or damage any soil, highway, or public road.

Waste material may be moved from the well site or battery site to a place where it may be disposed of without causing soil or water pollution with the approval of the Minister of Forestry, Lands and Wildlife if the place of disposal is on public lands or with the approval of ERCB if the place of disposal is not on public lands.

4.2.2 ERCB Information Letter IL 83-10

Information Letter IL 83-10 deals with the disposal of oil-field waste. Oil, gas, and pipeline operators are responsible for the containment and disposal of all waste. Oil and gas field waste that cannot be properly processed and disposed of within existing production facilities must be disposed of to an approved waste processing and disposal facility. The method of disposal of solid wastes or produced sand must be approved by ERCB.

General guidelines for a waste processing and disposal facility are:

1. The location must have little or no environmental impact with respect to noise, odour, and aesthetics.
2. An Alberta Environment Clean Air Licence is required if an incinerator is used in conjunction with the facility. Depending on the volumes of fluid and the type of operation, a Clean Water Licence may be required.
3. An approved waste processing and disposal facility should contain the following key elements:
   - Appropriate vessel(s) for waste receipts
   - Treating, separating, and recycling equipment
   - Centrifuge-type separator or equivalent
   - Adequate heat source
   - Adequate storage
   - An approved subsurface waste disposal facility
   - Satisfactory containment and disposal of surface water runoff
   - Appropriate diking
   - A cement or other approved impervious pit for containing spill debris if this service is provided

4. The method of disposal of solid waste and sludge material must be approved by the board.
5. Monthly records of oil and water receipts and dispositions must be completed and submitted to the Development Department, Calgary.
6. General:
   - Good housekeeping practices are to be followed.
   - Spacing of equipment must conform with present board regulations.

4.2.3 ERCB Information Letter IL 85-16

The intent of this information letter is to clarify and consolidate ERCB policy regarding the management of oily wastes. Oily waste is defined as waste materials containing oil generated during conventional oil, in situ oil sands, and heavy oil production such as sand sludges and slop oil, and oil containing snow, earth, or other debris collected as a result of containment and cleanup activities associated with an oil spill. The information letter outlines the following:

1. Requirements for permanent storage
2. Prohibition of temporary storage
3. Encouragement of waste reclamation
4. Discouragement of the disposal of oily waste on roads as a long-term solution
5. Approval procedures for permanent storage facilities and land treatment facilities

4.2.4 Alberta Environment Hazardous Chemical Act and Hazardous Waste Regulation

In 1987 December, the Government of Alberta enacted the Hazardous Waste Regulation (AR 505/87) which came into force on 1988 April 1. This regulation:

1. Identifies wastes that are managed as hazardous wastes under the powers of the Hazardous Chemicals Act and Hazardous Wastes Regulation

2. Specifies the type of manifest form to be used for tracking waste shipments
3. Specifies distribution of the manifest
4. Provides the Minister with the authority to require a bond from a person who operates a hazardous waste management facility
5. Requires immediate reporting of unlawful or accidental discharge, emission, escape, or spill of hazardous wastes
6. Specifies under what conditions hazardous wastes may be disposed of into landfills
7. Provides a list of hazardous wastes that may not be landfilled

The last two items probably generated the most interest in the petroleum industry.

Also, the following substantive measures were added:

1. Limits on the amount and time hazardous wastes may be stored
2. Small quantity exemption
3. Exclusion of all recycled materials
4. Exemption from manifesting for certain shipments of hazardous wastes
5. Requirement for immediate reporting of spills or other unauthorized releases
6. Prohibitions on landfill disposal

Section 2 outlines which waste is to be managed as hazardous waste under the Hazardous Chemicals Act and Hazardous Waste Regulation. It contains a list of wastes that are excluded by exemption, and makes reference to a list of hazardous chemical compounds and hazardous waste classification criteria that appear in the federal TDGA.

Certain wastes are exempt from the above as they are controlled under other legislation. This includes certain oilfield wastes resulting from exploration, development, or production of crude oil or natural gas. These include drilling fluids, produced waters, oily waste, fracture fluids, reformats, completion fluids, process and

runoff waters, spent iron sponge or similar sweeteners, and waste treater hay resulting from the exploration, development, or production of crude oil or natural gas approved pursuant to the Oil and Gas Conservation Act and regulations, the Oil Sands Conservation Act and regulations, or the Pipeline Act and regulations.

Sections 13 and 14 control storage of hazardous waste. Section 17 deals with landfill disposal and it reflects three management principles:

1. Liquid hazardous wastes may be disposed of only in landfills that have been provided with optimum protection for groundwater.
2. Any landfill which accepts hazardous waste must be operating under an approval granted by the Director of Standards and Approvals.
3. Certain hazardous wastes may not be disposed of in any landfill in Alberta.

Wastes that may not be sent to any landfill are:

1. Hazardous wastes that contain trichlorophenol, tetrachlorophenol, and pentachlorophenol in a concentration greater than 1000 mg/kg
2. Hazardous wastes that contain more than 50 parts per million of polychlorinated biphenyls
3. Hazardous wastes with a pH less than 2.0
4. Hazardous wastes containing any one or more of the following organic solvents in a concentration greater than 1000 mg/kg:

Acetone	Methanol
Benzene	Methylene chloride
N-Butyl Alcohol	Methyl ethyl ketone
Carbon disulphide	Methyl isobutyl ketone
Carbon tetrachloride	Nitrobenzene
Chlorobenzene	2-nitropropane
Cresols and cresylic acid	Pyridine
Cyclohexanone	Tetrachloroethylene
Ethyl acetate	Toluene

Ethyl benzene	1,1,1 and 1,1,2-trichloroethylene
Ethyl ether	Trichloroethylene
Isobutanol	
Xylene	

There is one additional prohibition on landfilling hazardous waste that should be noted. It is included in the Public Health Act, Waste Management Regulation, and prohibits disposal of hazardous waste into a modified sanitary landfill or dry disposal site.

4.2.5 Clean Air Act/Clean Water Act

There is a requirement to obtain a permit to construct under these Acts before building an industrial plant or facility. Before the facility may be operated, a licence to operate is required. Application forms outline the information that must be supplied for obtaining these approvals. Design and operating requirements are documented in guidelines issued by Alberta Environment.

4.2.6 Other Relevant Information

There are two other documents that are relevant sources of information for the management of oilfield-type wastes. The Guidelines for Industrial Landfills was published in 1987 June. It provides the approval, design, operating, monitoring, closure, and post-closure requirements as well as site restrictions relating to the establishment of an industrial landfill. Guidelines for Land Treatment of Industrial Waste was published by Alberta Environment in 1988 June.

4.3 SASKATCHEWAN LEGISLATION

4.3.1 Oil and Gas Conservation Regulations

The Department of Energy and Mines is responsible for regulating activities related to oilfield production. Section 76(2) of the Act prohibits the disposal of waste products, including drilling fluid, waste oil, or refuse from tanks or wells without the prior approval of the Minister. Subsection (6) prohibits such wastes that constitute a hazard to public health or safety or contaminate fresh water or available land.

4.3.2 Information Guidelines

Information Guideline GL 86-02 provides the guidelines for the construction and monitoring of ecology pits in Saskatchewan's Heavy Oil Area.

Information Guideline GL 86-01 provides the guidelines for on-lease and off-lease land application of freshwater drilling system fluids (muds and sludges).

On-lease disposal schemes are subject to the following criteria:

1. The minimum lease is to be calculated by
   $A = [Cl] \times V / 450\ 000$
   Where A is the minimum lease area to be used for spreading in hectares; [Cl] is chloride concentration of composite sample in mg/L; and V is the volume of sump material to be spread on lease in m^3.
2. Boron loading cannot exceed 5 kg/ha.
3. pH range is to be within 5.5 to 8.5.

Off-lease disposal schemes are subject to the following criteria:

1. pH range between 5.5 and 8.5
2. Electrical conductivity less than 7 mmhos/cm at 25°C
3. Chloride concentration equal to or less than 1000 mg/L
4. Sulphate concentration equal to or less than 2000 mg/L
5. Total dissolved solids equal to or less than 4000 mg/L
6. Spreading rate not exceeding 40 m^3/ha

Currently, waste oil and sludge from tanks can be spread on leases, lease roads, satellites, or battery sites with approval from the surface owner and Saskatchewan Energy and Mines (SEM). The municipality is responsible for the submission of an application to SEM for the disposal on municipal roads or right-of-ways. Collecting data, obtaining adjacent landowner approval, filling out the application form, etc., may be done by the operator and/or the municipality. The following areas should be avoided when applying production wastes:

1. Areas with sensitive land use, e.g., recreational areas, specialty crops, etc.
2. Areas with light textured soil
3. Areas within 100 m of surface water
4. Areas within 50 m of private or community wells
5. Areas where depth to groundwater is less than 5 m

Discussions with Saskatchewan's Department of Environment suggest that no oily waste or sand consisting of organic material should be landfilled. Clean sand can be landfilled within lease boundaries if the site is properly designed and monitored for contamination. Specific proposals made by the industry will be evaluated on an individual basis.

4.4 BRITISH COLUMBIA LEGISLATION

4.4.1 Petroleum and Natural Gas Act

Division 61 of the Drilling and Production Regulation provides some general statements dealing with formation water, oil, drilling fluid, waste, chemical substances, or refuse from a well, tank, or other production installation. Basically, it prohibits practices that would create a hazard to public health or safety or damage to the environment.

4.4.2 Waste Management Act

A comprehensive Special Waste Regulation (Reg 63/88) was enacted in 1988 by the Ministry of Environment and Parks. It defines special wastes as those listed in the federal TDGA and provides the following regulations and standards:

1. Minimum siting standards for all special waste facilities
2. Siting requirements, operational requirements, and performance standards for:
   - Recycle facilities
   - Short-term storage facilities
   - Treatment facilities
   - Incinerators and thermal facilities

- Mobile facilities
- Secure landfills
- Waste sites, surface impoundments, and land treatment facilities
- Long-term storage facilities

3. Prohibited management practices (i.e., mixing and dilution, underground injection, floating facilities, unauthorized discharge to municipal systems)
4. Management of waste oil, including:
   - Manufacture of pavement
   - Road construction repair or dust suppression
   - Use as a fuel
5. Effluent criteria for special waste facilities
6. Emissions criteria for special waste thermal treatment facilities
7. Waste prohibited from disposal in a secure landfill or a long-term storage facility, including:
   - Waste material that contains free liquids
   - Ignitable waste
   - Wastes that contain greater than 1 percent by mass of total organic carbon (in excess of natural composition)
   - Wastes that contain halogenated organic compounds greater than or equal to 1000 mg/kg
8. Analytical methods

4.5 U.S. ENVIRONMENTAL REGULATIONS

A variety of programs exist at the state and federal level to manage wastes that are related to the oil and gas industry. These include:

1. The Resource Conservation and Recovery Act (RCRA) was enacted in 1976 and required the Environmental Protection Agency (EPA) to (a) establish procedures for identifying wastes as either hazardous or nonhazardous, and (b) promulgate requirements for the management of both.

2. The Safe Drinking Water Act was passed in 1974, and regulations were subsequently promulgated for regulation of oilfield underground injection wells (i.e., Class II disposal wells).
3. The Clean Water Act was enacted in 1972 primarily to control point source discharges into surface waters of the United States (i.e., NPDES permits program).
4. The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), commonly known as Superfund, was passed into law in 1980 December. Superfund established a program to identify sites from which releases of hazardous substances into the environment might occur or have occurred, to ensure that they are cleaned up by responsible parties or the government, to evaluate damages to natural resources, and to create a claims procedure for parties who have cleaned up sites or spent money to restore natural resources.
5. The Federal Land Policy and Management Act of 1976 establishes comprehensive land use guidelines for the Bureau of Land Management, U.S. Department of the Interior on how to manage public lands under its jurisdiction.
6. The Federal Oil and Gas Royalty Management Act of 1982 was designed to assure proper and timely revenue accountability for production from onshore federal and Indian oil and gas leases; to address Outer Continental Shelf matters; to address lease reinstatement; to prescribe onshore field operation requirements for inspections and enforcement actions; to establish the basis for cooperation with states and Indian tribes for onshore federal leases; and to establish duties of lessees, operators, and others involved in the production, storage, measurement, and transportation or sale of oil and gas from onshore federal lands (i.e., national parks, reserves, native people lands, etc.)

7. State Environmental Performance Regulations: All state oil and gas regulatory agencies have regulations aimed at ensuring that the state's citizens and natural resources are protected from potential environmental damage. In the event problems are identified, all states have the authority to issue cease and desist orders; assess or seek administrative, civil, or criminal penalties; order cleanups; and, if necessary, ban further operations and sever an operator's pipeline connection.
8. Local government Oil and Gas Lease Agreements may impose obligations with respect to waste treatment, disposal, or reclamation that may be different or more stringent than state or federal regulatory requirements.

Hazardous waste treatment and disposal in the United States is regulated under RCRA Subtitle C regulations which are extremely stringent. Nonhazardous wastes are regulated under RCRA Subtitle D regulations which are less extensive and depend primarily on state controls. The 1980 RCRA amendments exempted oil industry exploration and production wastes from regulation under RCRA hazardous waste provisions (Subtitle C), and directed EPA to study such wastes and recommend appropriate regulatory action to Congress.

Under CERCLA, EPA has broad enforcement authority to require Potentially Responsible Parties (PRPs) to undertake cleanups or to recover costs incurred in conducting remedial actions from PRPs.

Courts have interpreted the statute to be retroactive in its application, to provide for strict liability without regard to fault, and in appropriate circumstances to impose joint and several liability. CERCLA provides operators with a significant economic incentive to properly manage disposition of solid wastes at both onsite and offsite locations to avoid being involved in expensive cleanup activities.

For example, it would be financially unsound to knowingly allow hazardous waste to contaminate a nonhazardous exploration and production waste site, making it a potential CERCLA site, and be named

as a PRP by EPA. EPA has taken the position that nonpetroleum "special wastes", although exempt from RCRA Subtitle C hazardous waste regulations, may nevertheless result in CERCLA liability if any of the constituents are "hazardous substances" as otherwise listed under CERCLA.

CERCLA provides for the exclusion of petroleum, including crude oil or any fraction thereof, from the definition of hazardous substance, pollutant, or contaminant. EPA has interpreted the petroleum exclusion to include, in their entirety, pure petroleum and pure petroleum fractions even through they contain substances that are otherwise listed as hazardous substances. Thus, EPA interprets the term "petroleum" to encompass crude oil, crude oil fractions, and refined products, such as gasoline, including any indigenous hazardous substances.

4.6 ANTICIPATED ENVIRONMENTAL REGULATIONS

4.6.1 Canada

Federal and provincial government guidelines and regulations are expected to be continuously amended and upgraded to reflect technological changes and industrial activities. The most important legislations to monitor are the federal TDGA and CEPA and their associated regulations since most provinces formulate their environmental regulations to meet federal requirements. For example, in the 1988 November "Canada Gazette", a list of hazardous substances to be determined by the leachate extraction test was added to Class 9.3 of List II, Schedule II of the TDGA Regulations. These added criteria are presented in Table B.1, Appendix B. Comparing Table B.1 and the waste characterization data in this study, some of the constituents such as chromium and lead are at or slightly exceed the limits listed in Table B.1. Another example are the substances listed on the CEPA PSL, a number of which may become regulated substances in the near future.

It is expected that these acts and regulations will be modified to contain a more comprehensive set of definitions, criteria, and procedures.

4.6.2 United States

To make some predictions about the future, it is necessary to review the historical events in the United States.

When RCRA was amended in 1980, Congress decided that wastes generated by oil and gas exploration and production operations required special consideration. The 1980 RCRA amendments exempted exploration and production wastes from regulation under RCRA hazardous waste provisions (Subtitle C) on the condition that EPA study such wastes and recommend appropriate regulatory action to Congress.

EPA conducted the study and submitted a report to Congress in 1987 December. In its report, EPA recommended the renewal of exemption for exploration and production waste under Subtitle C. However, the report also listed examples of waste treatment methods and general field practices that in specific instances have not been used in an environmentally-sound manner. At issue is not the practices themselves, but the lack of state regulations for overseeing the practices. These treatment methods/practices include:

1. Landfarming
2. Roadspreading
3. Pit construction
4. Surface water discharges
5. Central disposal and treatment facilities
6. Abandonment practices (existing and previously abandoned wells)
7. Arctic operations
8. Associated wastes (everything except drilling waste and produced water)

Subsequently, in the fall of 1988, an environmental group challenged EPA's decision to exempt "Associated Wastes" from Subtitle C regulations by filing a lawsuit against EPA. The litigation is ongoing.

Hence, the probability of the exemption being renewed for exploration and production wastes will depend on, to a large degree, the outcome of the litigation against EPA on this matter. Nevertheless, EPA has the authority under Subtitle D to promulgate more tailored criteria.

EPA activity and RCRA amendments after 1988 are likely to increase the emphasis on Subtitle D wastes (nonhazardous wastes) and establish additional minimum standards that state programs must include for Subtitle D waste management.

4.7 SUMMARY

Both Canada and the United States are continuously developing, amending, and upgrading their environmental protection acts and associated regulations such as TDGA, CEPA, and RCRA to improve the environment. As a result, industries, including oil production, will be required to meet more stringent environmental regulations and improve on current waste handling, treatment, and disposal practices. The oil industry is preparing to meet these requirements by undertaking treatment technology assessments and demonstration projects focusing on waste management.

5. CURRENT WASTE MANAGEMENT PRACTICES

This section provides a brief description of solid and sludge waste management practices currently employed by oilfield operators. In general, there are more stringent waste management practices associated with heavy oil production, particularly in the Lloydminster/Lindbergh area. Historically, conventional oil producers have been storing similar wastes in various forms or transferring the wastes to waste reclaimers. The reason for this difference in management approach is due to the greater volume and different physical properties of waste solids generated as a result of in situ heavy oil production. The techniques described in this section are currently employed by both conventional oil and heavy oil producers to handle finer particle size wastes.

5.1 OIL PRODUCTION PRACTICES

In conventional oil production, oil is recovered from the reservoir by natural pressure or by pumping. However, most fields in Alberta require some form of production enhancer, including water, polymer, caustic, or solvent. Depending on its water content, the production fluid is sent to a free water knockout vessel (FWKO) and on to a treater. The FWKO removes the water in the fluid by gravity. The treater removes additional water to achieve pipeline specification by the addition of heat, chemicals, and some method of coalescence. Sales grade crude oil is stored in storage tanks. Produced water from the FWKO and treater is sent to a skim tank, which is normally followed by disposal well injection.

Solid waste and sludges from conventional oil production include:

1. FWKO sludge
2. Treater interface material
3. Storage tank bottom sludge
4. Skim tank interface material
5. Spill cleanup material

In addition, some older batteries in Alberta and Saskatchewan have waste holding ponds and/or emergency storage pits. Waste holding

ponds are usually unlined, earthen ponds that collect a wide range of waste fluids, surface runoff, and solids produced in all phases of oilfield development and operation over many years. Emergency storage pits are usually unlined, earthen ponds used to catch overflows from crude oil storage tanks. Free oil collected in these pits is normally pumped out with vacuum trucks.

In heavy oil operations where flowline gathering systems are not feasible, field separator tanks are employed at satellite sites to separate oil, water, and sand by gravity. Following the removal of oil, which is transported to production batteries, and produced water, which is usually trucked separately to the production battery and disposed of by deep well injection, the sand is periodically removed and transported to concrete and, in some cases, lined ecology pits for storage.

This study addresses the handling and treatment of only the finer particle size wastes resulting from heavy oil production operations. Heavy oil produced sands are not part of this study scope.

In cases where field tanks are not used, the produced fluid is sent via flowline to the production batteries where FWKO vessels and fired heater treaters or coalescers separate the oil, water, and solids. These separators and treaters are routinely desanded into desand pits and the solid waste transferred to ecology pits for storage.

5.2 CURRENT WASTE MANAGEMENT PRACTICES

Current waste handling/treatment/disposal practices for both conventional oil and heavy oil producers include:

1. Onsite storage of spill debris
2. Transfer of waste to waste reclaimers
3. Use of waste material for road construction
4. Offsite treatment

5.2.1 Onsite Storage

In both conventional oil and heavy oil production operations, spill debris and cleanup materials (e.g., CanWeb, gypsum, straw)

resulting from pipeline breaks, spills, etc., are normally stored onsite in what is sometimes referred to as an ecology pit.

At the ecology pit, most operators segregate the waste into finer particle size sludges and denser sands as much as possible. Normally, the finer sludges are stored in concrete pits. Well-designed facilities will allow runoff from the storage area to also be collected in the concrete pits.

5.2.2 Waste Reclaimer

Slop oil and sludges with high wax and asphaltene content and other difficult to handle wastes are routinely sent to waste reclaimers. Treatment and disposal techniques employed by waste reclaimers are typically gravity separation, heat treatment, landfarming, injection well disposal, and storage. Waste received at the reclaimer's site is generally dumped into a decanter tank and steam is provided to heat the contents. Free oil is skimmed off as much as possible. Recovered oil is sold and produced water disposed of via an injection well. The remaining sludges are either landfarmed or stored. The disposal cost depends on the oil, water, and solids content of the waste and can be up to $\$200/m^3$.

Although waste reclaimers are well suited to handle slop oils having high oil and low solids content, they are not well equipped to treat waste sludges containing high levels of fine particles and contaminated with significant levels of salt and heavy metals.

5.2.3 Road Construction

As onsite storage facilities such as ecology pits become filled, waste sludges are applied on road surfaces with a bulldozer or front-end loader, and waste oils are normally dispensed through a spreader bar from a pressure truck. A grader then mixes the waste material with road surface clays by blading the mixture back and forth across the road. Some operators improve on the roadspreading method by using the waste material for roadbed construction. Construction methods

vary from one company to another. In some cases, waste material is placed between a bottom clay base and a clay cap, and then backfilled. In other cases, waste material is blended with natural aggregate. Thus, the cost and rate of success of this method of disposal depend on the physical characteristics of the waste and method of construction used. The cost was reported to vary from $\$6/m^3$ to $\$50/m^3$.

The finished road surfaces are excellent in some cases but poor in others. When too much oil is applied or the natural aggregate to waste material ratio is too low, the road surface tends to become too soft and wet in the summer.

The effects of road application with oily waste have not been well documented. Some operators have installed monitoring wells along the ditches to collect seepage data.

Disposal of oily waste on municipal roads is becoming more difficult and expensive because:

- Application/construction standards do not exist. This has led to a wide range of quality of road surfaces of which some are not well accepted by the public and regulatory agencies.
- Operation can only be carried out in the few short summer months. Storage of the waste material is required for the remainder of the year.
- Oil companies are not in the road construction business; therefore, project execution is often inefficient.
- There is increasing public concern regarding waste disposal practices and their impact on the environment.
- Operators are expected to keep the road surface continually maintained in good condition.
- In some areas, the volume of waste materials greatly exceeds that which can be applied to roads.
- Long-term liability and monitoring requirements over a large, scattered area is highly undesirable.

5.2.4 Landfill Disposal

In Alberta, industrial landfills are classified into Class I, II, and III in order of sophistication, depending on the type of waste to be disposed of. To dispose of the hydrocarbon-contaminated solid waste material considered in this study, a Class II landfill would likely be required as a minimum requirement.

Cleaned sands may in some cases be disposed of in a Class III landfill. At least one operator in the Lindbergh area has used the landfill method for disposing of cleaned sands. In this case, the landfill is located in a low-lying area (i.e., a slough). The waste material is placed between a clay bottom layer and a clay cap. It is then backfilled and seeded to blend naturally with the adjacent landscape.

5.2.4 Landfarming/Landspreading

Landfarming has been used by several operators in Canada for the treatment and disposal of oily sludges from refineries and waste reclaimers. Landfarm operations are currently operating in Taylor and Prince George, British Columbia; Drayton Valley, Edmonton, and Fort Saskatchewan, Alberta; Moose Jaw, Saskatchewan; Oakville and Mississauga, Ontario; and other places. Landfarming or landspreading involves the application of petroleum wastes to the upper soil zone for decomposition by microbes and incorporation into the soil. It involves an even spreading of sludge, a period of sludge drying at the soil surface, and subsequent tilling of the sludge into the top 15 - 20 cm of the soil. Afterward, the land is usually tilled again periodically to aerate the soil and promote microbial decomposition of hydrocarbons. The process of landspreading has some similarities to agricultural practices as similar machinery is used and similar management of the soil is needed for the landfarm to be economically run without environmental or safety problems. Unlike an agricultural operation, no crops are grown and no livestock is raised on a landfarm.

Landfarming can be a cost-effective and environmentally safe process for some types of wastes. However, its suitability for wastes containing high concentrations of salt and organic material and heavy metals such as chromium and lead is questionable.

5.3 SUMMARY

Some of the current practices for disposal of oilfield production wastes with characteristics outlined in Section 3 of this report are now becoming more and more difficult to implement. Disposal of oily waste material on municipal roads will decrease because of increasing public concern of its impact on the environment and because regulatory bodies such as ERCB are discouraging this practice. Also the volume of waste materials accumulated now greatly exceeds the amount that can be applied to roads. Landfarming and landspreading have been used by several operators in the past for disposal of oily wastes. However, oily wastes containing high levels of salt and organic material and metals such as chromium and lead are not suitable for land disposal because of their long-term environmental risk.

A number of producers have used waste oil reclaimers to treat and dispose of their waste sludges. Although waste oil reclaimers are well suited to handle slop oils having high oil and low solids content, they are not currently equipped to treat waste sludges containing fine particle size solids and high levels of salt and heavy metals. Current technologies employed by waste reclaimers may be upgraded or modified with new and/or developing technologies and processes as described in Section 6 to handle these difficult to treat waste sludges and solids.

It is apparent that the oil industry's current waste disposal practices will be either severely restricted because of more stringent environment controls or prove to be unsuitable to treat fine-particle-sized, oily sludges contaminated with salt and heavy metals. As a result, there will be an increasing need to develop new technologies and processes capable of treating and disposing of these wastes.

6. OVERVIEW OF TREATMENT/DISPOSAL TECHNOLOGIES

This section presents an overview of various treatment and disposal technologies that may be applicable to the types of oilfield wastes discussed in Section 3. Previously, it was established that the sludge and solid wastes which would be addressed in this study contain varying amounts of oil, salt, and heavy metal contamination and have a significant portion of fine materials (i.e., a particle size less than 60 microns) in their solid fraction. Due to the range of contaminants present in these wastes and the variability of the physical characteristics of these wastes, many of the potentially suitable treatment options may need to be high-technology-based processes. Current disposal methods such as landfarming/landspreading and road application may only be suitable for some of these wastes. Treatment and disposal of offsite oil reclaimers may only be suitable when there is a recoverable amount of oil product.

Treatment technologies having potential application for the above described waste type were identified and grouped into six general categories. These are:

1. Solvent extraction
2. Aqueous extraction/leaching
3. Thermal treatment
4. Biodegradation treatment
5. In situ treatment
6. Other treatment/disposal technologies (including land application methods of disposal)

The objective of this section is to provide the reader with an overview of each of the six general categories and their advantages and disadvantages. A more detailed discussion of individual processes within these categories is presented in Section 7.

6.1 SOLVENT EXTRACTION

6.1.1 Overview

Solvent extraction treatment is based on the properties of a fluid at or near its critical point. Such a fluid behaves like a liquid

organic solvent, in that it can dissolve significant amounts of oil or other organic substances. But at the same time it behaves like a gas, making efficient recovery of the solvent possible. In a typical process, waste enters near the bottom of an extractor vessel and the solvent is fed countercurrently into the top. The organics (oil) in the waste dissolve into the solvent. By knowing the properties of the solvent and then manipulating the vessel's temperature and pressure, the solvent, oil, water, and solids phases can be separately extracted. Solvent extraction can be applied to liquid wastes, sludges, and solids. Removal of oil from solids is usually higher than 90 percent.

A generic treatment train for solvent extraction technologies is shown in Figure 6.1.

The first step in the process is to prepare the feed. Solid material may require slurrying or dewatering prior to feed. Also, screening, pH adjustment, and homogenization may be required. Once conditioned, the waste is fed into the extraction vessel countercurrent to the solvent feed. A single unit or a multi-staged unit is possible in this step. The extraction unit produces two streams: a solvent/oil/ water stream and a solvent/solids stream. The solvent/oil/ water stream is fed to a decanter where the water is removed for disposal. The solvent and oil are then further separated by heat. Recovered oil is discharged back to the battery for processing. The recovered solvent is recycled back to the extraction unit. The solvent-contaminated solid stream is discharged into a dryer where the solvent is removed and recycled. The produced solids are then disposed of. Stabilization or other treatment may be required prior to disposal.

6.1.2 Advantages of Solvent Extraction

1. Organic removal efficiencies of 90 to 95 percent are possible in many applications.
2. At least two well-demonstrated processes are commercially available. A third could be available by late 1989.

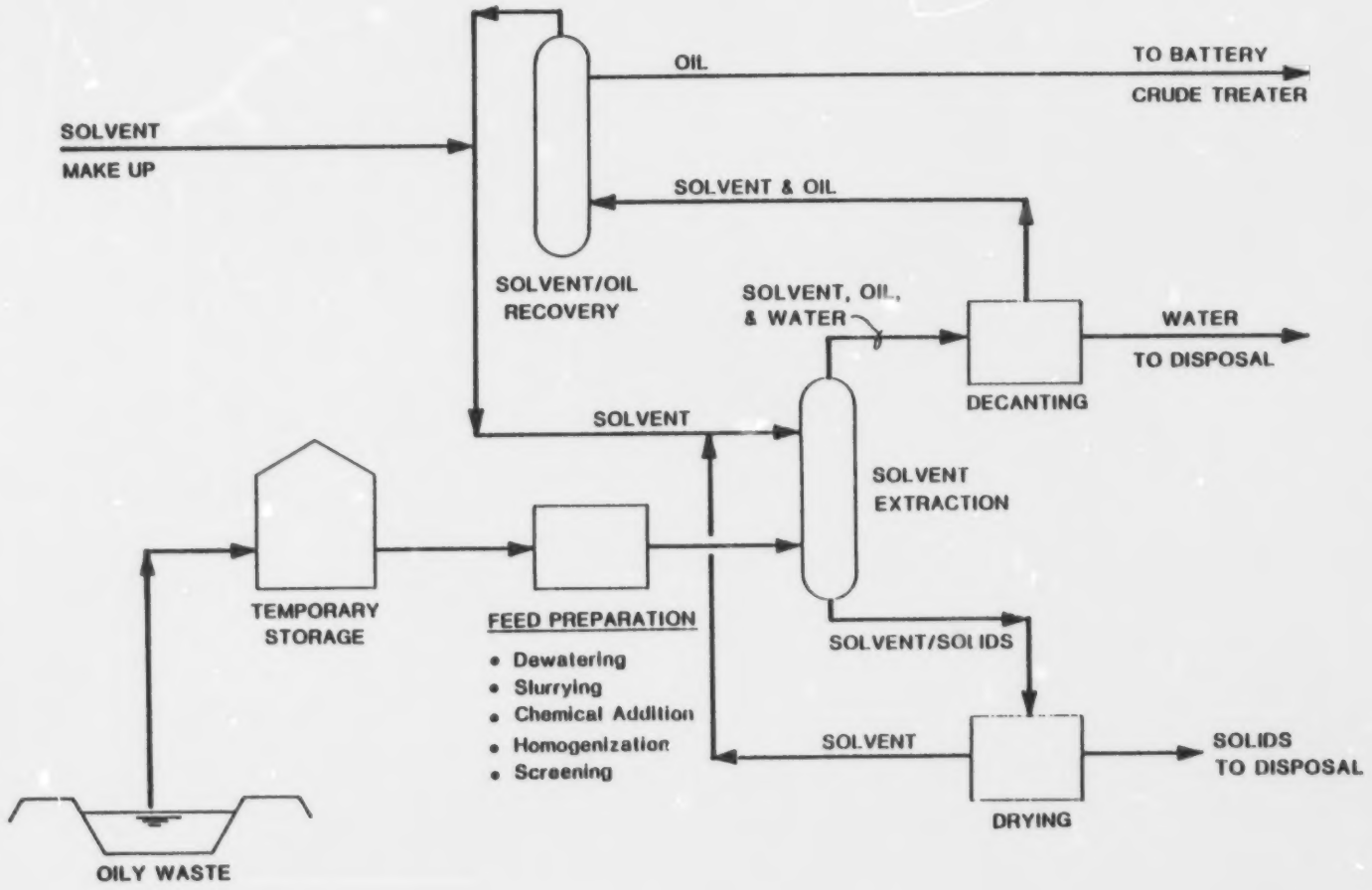

Figure 6.1

GENERIC TREATMENT TRAIN FOR SOLVENT EXTRACTION TECHNOLOGIES

CH2M HILL

3. The technology can be adapted to process a wide range of waste types.
4. The technology can be easily tested using bench-scale or small pilot-plant-scale equipment.
5. The technology uses familiar and well-developed process components.

6.1.3 Disadvantages of Solvent Extraction

1. Insufficient removal of solvent from the solids could result in solvent-contaminated solids (instead of oil-contaminated solids).
2. Depending upon the solvent used, personnel safety, equipment complexity, and the potential for fugitive air/odour emissions can contribute significantly to the cost of the project. Many solvents are themselves hazardous.
3. Residual solids may still contain undesirable constituents such as salt and may require further treatment or special disposal techniques.

6.2 AQUEOUS EXTRACTION AND LEACHING

6.2.1 Overview

Aqueous extraction and leaching (commonly referred to as soil washing) is applicable to situations in which a solid or semi-solid material contains contaminants that are soluble in the aqueous solution. The solid material must be permeable to the aqueous solution and must not be soluble in the solution. In order for the process to be effective, the contaminants must not adsorb strongly to the solid.

The aqueous solution infiltrates the contaminated waste solid, leaching out soluble contaminants. Soluble contaminants pass from the solid to the aqueous phase and are removed from the system along with the aqueous solution. The effectiveness of this treatment

depends on the permeability of the solid phase and on the contaminant partition coefficient between the solid and aqueous phases.

A generic treatment train for the aqueous extraction and leaching process is shown in Figure 6.2.

In the first step, dry or damp waste is mixed with water to form a slurry. Enhancers such as heat, alkali, acid, detergents, diluent, etc., are mixed with the slurried waste in a conditioning vessel. Skimmings from this vessel are drawn off for disposal. Treated solids are removed for further dewatering/disposal. The aqueous phase, containing extracted contaminants and some fine solids, is withdrawn and processed in a separator. Fine solids are removed from the separation device for further treatment/disposal and the aqueous solution is treated for either recycle or disposal.

6.2.2 Advantages of Aqueous Extraction and Leaching

1. The effectiveness of the aqueous extraction and leaching process can generally be predicted by using known chemical properties.
2. There is extensive experience with the process in other similar applications such as tar sands extraction and soil washing.
3. The technology can be adapted to process a wide range of waste types.
4. The technology can be easily tested using bench-scale or small pilot-plant-scale equipment.
5. The technology uses familiar and well-developed process components.

6.2.3 Disadvantages of Aqueous Extraction and Leaching

1. Solid waste material must be reduced in size and adequately processed (slurrying) to allow thorough contact with aqueous media.
2. The residual solid phase may still contain traces of hazardous materials.

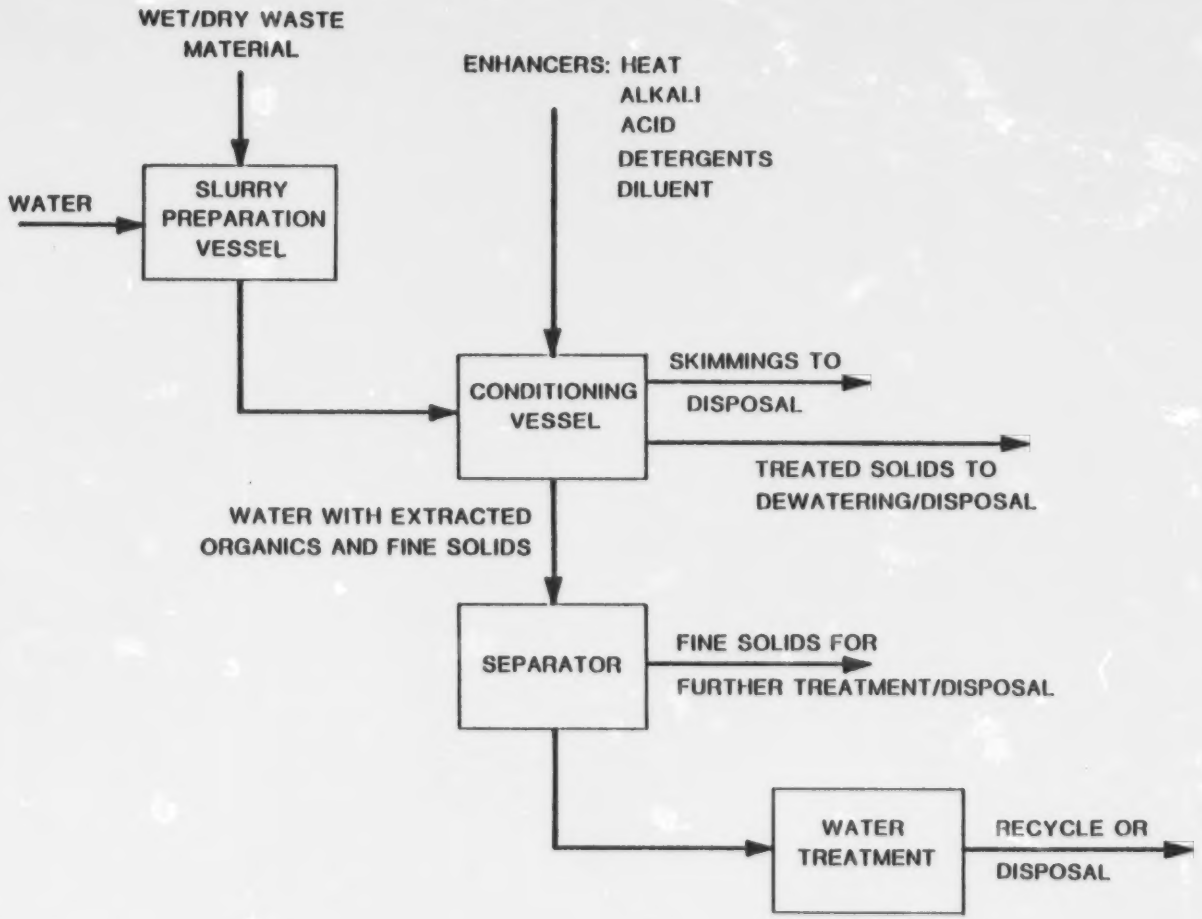

Figure 6.2

GENERIC TREATMENT TRAIN FOR AQUEOUS EXTRACTION AND LEACHING PROCESS

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3. The technology requires a fresh water source and the wastewater resulting from the leaching process may contain hazardous contaminants and require proper treatment and disposal.
4. Waste materials consisting of a large proportion of fine solids are not well suited for this process.
5. Residual solids may still contain undesirable contaminants and may require further treatment or a special disposal technique.

6.3 THERMAL TREATMENT

6.3.1 Overview

Thermal treatment of petroleum production waste removes water and volatile organics from oil/water/solids mixtures by heating the mixture and causing vaporization. The feedstock for a thermal treatment unit could be a raw waste without pretreatment or a residue from an initial mechanical treatment process.

In incineration, waste materials are thermally destroyed in a controlled oxygen-sufficient environment. Generally, products include carbon dioxide, water, and ash. Many different types of incinerators with varying capabilities exist.

In pyrolysis, materials are thermally destroyed in an oxygen-deficient environment. Pyrolysis by itself produces gases that subsequently have to be burned or incinerated because they are products of incomplete combustion and are rich in organics, but it has some unique applications for hard-to-burn materials. The pyrolysis process generates carbon and hydrocarbons if no air is present or carbon plus carbon monoxide and organic gases if some air is present along with hydrogen and possibly halogens (if halogenated materials are present in the waste). Pyrolysis, as an industrial process, has been in use for many years.

Figure 6.3 illustrates schematically a generic treatment train for thermal technologies for the treatment of petroleum production waste sludge/solids.

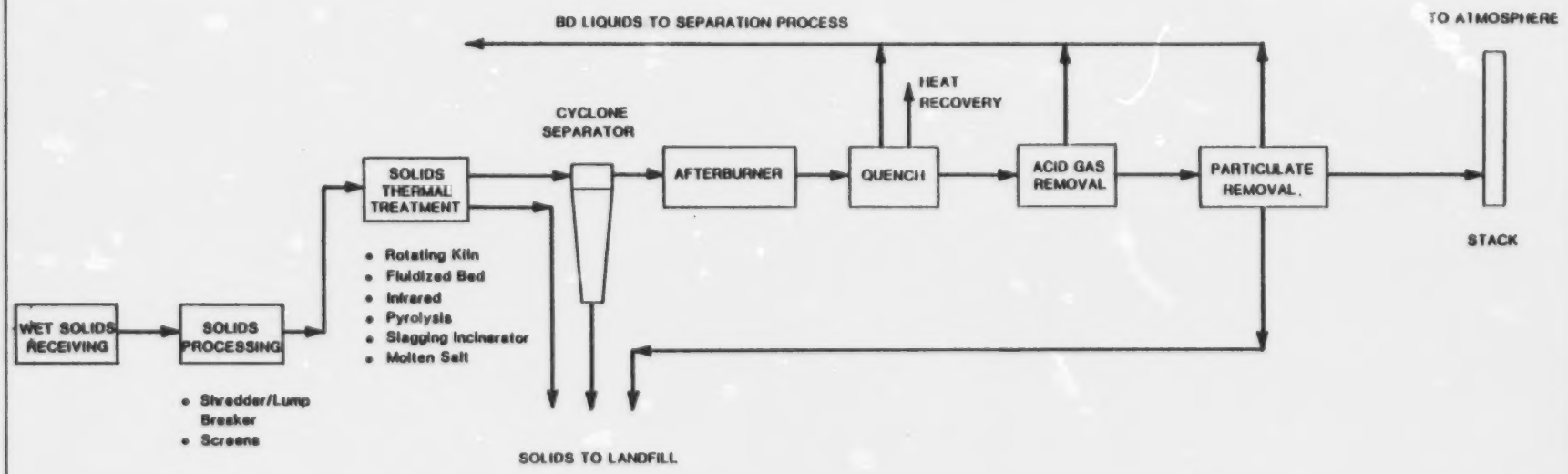

Figure 6.3

GENERIC TREATMENT TRAIN FOR THERMAL TECHNOLOGIES

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In the first step, for proper burning, the waste material must be significantly reduced in particle size by techniques such as crushing, grinding, and shredding. The actual combustion device can be any one of a number of different types/designs. The specific combustion devices addressed in this study are listed in Figure 6.3.

Cyclone separators are sometimes installed between the primary combustion device and the afterburner to reduce the carryover of residual solids in the gas stream.

The secondary combustion chamber, or afterburner, is used to reheat products of combustion to a higher temperature in the presence of excess air to destroy any organics present.

A quench is provided to cool the gas stream to a temperature at which commercially available fabric filters can be used downstream of the afterburner.

Particulate removal can also be accomplished by using wet scrubbers, wet electrostatic precipitators, or dry electrostatic precipitators.

Wastes containing halogens, sulphur, or phosphorus need special equipment to remove their derivative compounds after combustion is complete. Halogens in the waste will form halogen acid gases in the thermal process if sufficient hydrogen is present for hydrolysis. Acid gas removal equipment could be systems based on wet alkali or dry lime.

6.3.2 Advantages of Thermal Treatment

1. It significantly reduces the volume of waste to minimize final disposal requirements.
2. It reduces the toxicity of the waste by combustion of organics to carbon dioxide and water.
3. It stabilizes the contaminants to reduce their mobility.
4. It destroys waste immediately.
5. It's appropriate for many forms of waste materials, including solids.
6. Waste heat recovery may be possible.
7. It has significant operating experience for many systems.

6.3.3 Disadvantages of Thermal Treatment

1. Supplemental fuel is required for startup and may be required to maintain combustion.
2. It requires licensed operators.
3. It produces ash that may itself be considered hazardous material, requiring disposal.
4. It has a potentially lengthy siting and permitting process.
5. Significant material handling, preprocessing, and post-processing may be required.
6. Control of air emissions from the process may require costly equipment.

6.4 BIODEGRADATION TREATMENT

6.4.1 Overview

This method usually involves enhancing the contaminant biodegradation activity of native soil microorganisms, using existing, well defined, and easily implemented methods. These methods include manipulation of the pH, oxygen, nutrient, and moisture content of the soil as well as the temperature of reaction.

The degree of contaminant biodegradation is often limited by oxygen availability. Oxygen availability can be increased by promoting the diffusion of oxygen through soil pores.

Many soils contain most of the inorganic nutrients required for microbial metabolism. Nitrogen and phosphorus are the nutrients most often present in limited concentrations. Microbial activity can sometimes be dramatically increased by application of these nutrients. Potassium supplements are also sometimes required. While many microbes can persist for extended periods in the absence of unbound water, the presence of free water is required for metabolism. Microbial activity generally increases with increasing soil moisture content; however, saturation of soils can lead to anoxic conditions. Control of soil moisture content is therefore important.

Microbial activity is also greatly influenced by temperature. It decreases with temperature and therefore may limit application to a few months of the year.

Waste constituents that are potential condidates for biodegradation include most organic compounds and organic/inorganic complexes.

6.4.2 Advantages of Biodegradation Treatment

1. It provides treatment as well as disposal.
2. It is relatively simple to operate.
3. Costs are generally attractive in comparison with other technologies.

6.4.3 Disadvantages of Biodegradation Treatment

1. Cold weather can decrease or inhibit treatment.
2. There is the potential for groundwater or surface runoff contamination (landfarming/composting).
3. Odours and aesthetics are concerns.
4. It may require large areas of land (landfarming/composting).
5. Produced solids will require disposal.
6. It has a potential risk of contaminating wildlife.
7. Constituents in waste material such as salt and heavy metals (chromium and lead) may prohibit land application.

6.5 IN SITU TREATMENT

6.5.1 Overview

The available in situ treatment technologies include thermal, chemical, and biological processes. Thermal processes use an energy source to create heat to either volatilize the organics or melt the contaminants and surrounding mass into a vitreous mass. In the chemical

processes, chemical is added to stabilize the waste (i.e., limit solubility or decrease mobility of the waste) before being encased by a liner or before being solidified. Biological processes use microorganisms, usually those already existing in the waste, to metabolize and decompose the organic contaminants.

In situ treatment technologies for the petroleum production waste considered in this study are applied in place or require that the waste be placed in a container or in an excavated pit for treatment. The feedstock could be in situ waste, soil without treatment, or a residual from an initial mechanical treatment process. Many of the in situ treatment processes are affected by waste and site characteristics such as high moisture content or soil permeability.

Most organic compounds and organic/inorganic complexes are potential candidates for in situ treatment processes, and the compatibility between waste and treatment can be easily verified by bench-scale testing.

The status of these technologies ranges from pilot testing for thermal processes to commercial applications for chemical processes.

6.5.2 Advantages of In Situ Treatment

1. Treatment can be performed with waste in place without disturbing it or transporting it.
2. It provides treatment as well as disposal in one step.

6.5.3 Disadvantages of In Situ Treatment

1. Application of the technology is affected more by site and waste characteristics than other technologies.
2. It is difficult to confirm complete treatment without extensive sampling and testing in the field.
3. Pilot testing will have to simulate site conditions.
4. Some in situ treatment processes are not yet commercially available.
5. It has potentially high operating costs in comparison with other technologies.

6. Constituents in the waste material such as salt and heavy metals may produce a residual that has long-term environmental risk possibilities.

6.6 OTHER TREATMENT/DISPOSAL TECHNOLOGIES

Other treatment/disposal technologies include processes that recover oil for reuse and simple physical treatment to separate oil from water and solids. Some of these technologies/processes such as Colt Treater Oleophilic Sieve and gravity separation are low technology options which are applicable for treating those wastes where oil/water/solids separation is necessary and contaminants such as salt and heavy metals are in low concentrations. These processes can also be used in combination with high technology processes as an effective phase separation pretreatment step.

Other disposal methods/processes listed in this category, including landfill, Hot-Mix Asphalt, and Aglofloat, have potential application to either treat/handle specific wastes or, used in combination with other high technology processes, to provide a means of final solid residue disposal. These technologies are discussed in detail in Section 7.

7. SUMMARY OF APPLICABLE PROCESSES

This section summarizes and compares individual treatment processes under each of the six general categories described in Section 6. The processes presented here range from conventional, simplistic methods using gravity for phase separation to highly sophisticated thermal technologies for contaminant destruction. The objective of this section is to introduce to the reader the advantages and disadvantages of each process.

The ideal treatment technology is one that is low cost, simple to operate, capable of treating wastes containing a significant portion of fine particles, capable of separating oil/water from fine solids, and capable of generating a residual solid which is dewatered, desalted, and heavy metals removed and/or immobilized. It is doubtful if any one single process/technology is able to achieve all of the treatment objectives stated above for a waste containing the wide range of contaminants and exhibiting the varied characteristics previously described in Section 3. More realistically, some of the high-technology-based options coupled with low technology processes may be able to offer the best solution.

7.1 SOURCES OF INFORMATION

A literature survey was carried out on two levels. Externally, a commercially available computerized database search was employed. The databases searched included:

1. Enviroline (Corp. R.R. Bowker Company 1988)
2. Canadian Environment

Internally, a CH2M HILL computer-based database developed for U.S. EPA Superfund work was used. In addition, information was obtained from information collected by CPA, internal and external reports, vendors' information packages, and technical conference proceedings. The documents reviewed are listed in Section 11, Bibliography. The selection of processes for evaluation is based on information available at the time of preparing this report. It is not intended to include all

technologies in various stages of development in the marketplace. Table 7.1 presents the trade names of individual treatment processes under six general categories. Low-technology-based processes/methods currently used to treat and dispose of some wastes, such as landfill, landfarming, gravity separation, etc., are listed because they are well suited for a portion of the wastes generated by the oil producing industry. However, for a waste stream containing fine particles, hydrocarbons, salt, and heavy metals, a more advanced emerging treatment process/technology will most likely be required.

7.2 COMPARISON OF PROCESSES

This section is presented in a table format. Tables 7.2 to 7.7 deal with solvent extraction, aqueous extraction/leaching, thermal treatment, biodegradation treatment, in situ treatment, and other treatment/disposal technologies, respectively. A brief description, the advantages, and the disadvantages are provided for each process. A more detailed description of each process is provided in Appendix D.

The information provided in this section, supplemented by the information presented in the previous sections of this report, forms the basis for the assessment of treatment processes in Section 8.

Table 7.1 Applicable Treatment Processes

Solvent Extraction Treatment	Aqueous Extraction/ Leaching	Thermal Treatment
CF Systems Extraction	U.S. EPA Mobile Soil Washer	Rotary Kiln
B.E.S.T.	HWZ Soil Washing	High Temperature Slagging Incineration
Hot Toluene Fluid Extraction	Heidemij Soil Washing	Fluidized Bed
BP Oil Solvent Extraction	Oil CREP	Molten Salt
	Harbauer Soil Washing	Infrared
	MTA Soil Washing	Taciuk Processor
	Hot Water Extraction	Electric Pyrolyzer
	RTR/Gulf Sludge Conditioning	

Biodegradation Treatment	In Situ Treatment	Other Treatment/Disposal Technologies
Soil Slurry Biodegradation	Radio Frequency	Industrial Landfill
Landfarming/Land Treatment	Vitrification	Hot-Mix Asphalt
Composting	Solidification/ Fixation	Aglofloat
	Biological	Colt Treater
		Oleophilic^{R} Sieve
		Gravity Separation

Table 7.2 Solvent Extraction Treatment Technologies

TECHNOLOGY	ADVANTAGES	DISADVANTAGES
CF Systems		
CF Systems of Waltham, MA, developed a process using propane as a solvent to separate organics from solids, sludges, and water solutions. Waste to be treated is screened, neutralized, and thickened prior to extraction. Produced solids are dewatered and disposed of. Propane is recompressed for reuse.	o Technology is field demonstrated for similar types of waste material considered in this study and is commercially available. o Can process a wide range of waste types. o Can accommodate either fixed or mobile applications. o No air emissions except for fugitive emissions which are controllable. o Because of the low boiling point of propane, the possibility of solvent-contaminated solid residue is eliminated. o Significant reduction of hydrocarbon, metal, and salt contents in the produced solids. o Propane is readily available and relatively inexpensive, and handling practices are well established.	o The use of propane requires tightly sealed pumps, tanks, vessels, and accessories which can add to the cost of constructing a plant. Personnel safety is also a concern. o Requires trained operators. o Propane is a listed dangerous goods under TDGA. o Residual solids may still contain enough contaminants such as salt and metals to make disposal difficult. o Wastewater generated will probably require further treatment prior to disposal/ discharge.
B.E.S.T.		
The Basic Extraction Sludge Treatment system was developed by Resources Conservation Company of Bellevue, WA. It uses triethylamine (TEA) as a solvent for the cleanup of oily sludges and solids. Waste to be treated is screened, neutralized, and thickened prior to extraction. Produced solids are dewatered and dried. The solvent is recovered for reuse.	o Technology is field demonstrated for similar types of waste material considered in this study and is commercially available. o Can process a wide range of waste types. o Can accommodate either fixed or mobile applications. o No air emissions except for uncontrolled fugitive emissions. which are controllable. o Significant reduction of hydrocarbon, metal, and salt contents in the produced solids.	o Triethylamine has a strong, fishy odour and if emitted can present an odour problem. o Contamination of residue solids with the solvent is possible. o Requires trained operators. o Triethylamine is a listed dangerous goods under TDGA. o Residual solids may still contain enough contaminants such as salt and metals to make disposal difficult. o Wastewater generated will probably require further treatment prior to disposal/ discharge.

Table 7.2 Solvent Extraction Treatment Technologies (concluded)

TECHNOLOGY	ADVANTAGES	DISADVANTAGES
Hot Toluene Fluid Extraction		
This process is being developed by Tricil Limited. It used heated toluene (80°C) as a solvent to treat hydrocarbon-contaminated sludges and solids.	o No air emission except for fugitive emissions which are controllable. o Oil removal efficiency similar to the CF System and B.E.S.T. o Significant reduction of hydrocarbon, metal, and salt contents in the produced solids.	o Process still in early pilot plant development stage. Very limited information is available. o Toluene is a listed dangerous goods under TDGA. o Elevated operating temperature requires design consideration for personnel protection. o Residual solids may still contain enough salt, metals contamination to make disposal difficult. o Wastewater generated will probably require further treatment prior to disposal/ discharge.
BP Solvent Extraction		
BP Oil has developed a batch process for the cleanup of oily waste solids and sludges using propane and another light hydrocarbon solvent. Waste to be treated is screened, neutralized, and dewatered prior to extraction. Produced solids are dewatered and chemically stabilized in one step. Propane is recompressed for reuse or flared.	o Technology is field demonstrated for similar types of waste material considered in this study. o Can accommodate either fixed or mobile applications. o No air emission except for fugitive emissions which are controllable. o Can process a wide range of waste types. o Oil removal efficiency similar to the CF system and B.E.S.T. o Propane is readily available and relatively inexpensive, and handling practices are well established.	o Commercial plant not yet available. o Propane is a listed dangerous goods under TDGA. o Only limited cost information is available regarding the process. o Although there is a significant reduction of hydrocarbon in the produced solids, residual solids may still contain contaminants such as salt and heavy metals, making disposal difficult. o Wastewater generated will probably require further treatment prior to disposal/ discharge.

Table 7.3 Aqueous Extraction and Leaching Technologies

TECHNOLOGY	ADVANTAGES	DISADVANTAGES
Oil CREP This process was developed in Germany mainly for the remediation of hydrocarbon-contaminated coarse soils. The process uses a combination of surfactants, solvents, and aromatic hydrocarbons to extract oil.	o Mobile units available. o Demonstrated full-scale operating plant in Europe. o No air emissions. o Acceptable reductions of hydrocarbon, metal, and salt content in the produced solids.	o Process likely will have problems treating wastes with a large fraction of fine particles. o No experience with wastes containing heavy metals. o Technology not commercially available in North America. o Some of the chemical additives may themselves be hazardous. o Contaminant levels in residual solids will have to be determined by pilot testing.
Harbauer Soil Washing This process uses a number of mechanical process components and chemical additives to clean contaminated soil. The process uses a unique low frequency vibration step to dislodge contaminated fines from the soil matrix.	o Process can treat wastes containing fine particles. o Demonstrated full-scale operating plant.	o Potential air emissions. o Technology not commercially available in North America. o Process has some components which add to its complexity. o Only limited success treating wastes containing heavy metals. o Some of the chemical additives may themselves be hazardous. o Process likely will have problems treating wastes with a large fraction of fine particles.
MTA Soil Wash This process, patented by MTA Remedial Resources Inc., uses technologies developed by the mineral processing industry to physically separate three phases: contaminant, aqueous solution, and sediment.	o Mobile system available. o Demonstrated full-scale field unit. o Process components relatively simple and previously used in industry.	o Limited experience with the type of wastes in this study. o Process likely not cost effective for treating wastes having a large fraction of fines.

Table 7.3. Aqueous Extraction and Leaching Technologies (continued)

TECHNOLOGY	ADVANTAGES	DISADVANTAGES
U.S. EPA Soil Washer		
This mobile treatment system was designed for water extraction of a broad range of hazardous materials from spill-contaminated soils. The technology was originally developed to remove oil from beach sand resulting from oil spills.	o Mobile systems available. o Demonstrated in full-scale field trials in similar applications. o Acceptable reductions of hydrocarbon, metal, and salt content in the produced solids are expected.	o Air emissions from extraction unit may require control equipment. o Requires fresh water source and wastewater disposal. o An increase in fines in feed may result in a decrease in throughput. o Contaminant levels in residual solids will have to be determined by pilot testing.
HWZ Soil Washing		
This process was developed in the Netherlands and is based on the general standard techniques of extraction/leaching. The process uses a variety of chemical additives, depending on the nature of the contaminants in the waste.	o Low energy consumption. o No air emissions. o Full-scale plant operating in Europe. o Applicable to wastes containing a wide range of contaminants. o Acceptable reductions of hydrocarbon, metal, and salt content in the produced solids are expected.	o Process has a number of components which adds to its complexity. o Technology not commercially available in North America. o Some of the chemical additives may be themselves hazardous. o Not cost effective for treating wastes having a large fraction of fines. o Contaminant levels in residual solids will have to be determined by pilot testing.
Heidemij Soil Washing		
This process is based on froth flotation and is an extension of processes used in the mining industry. The process was developed in the Netherlands.	o Mobile units available. o Demonstrated full-scale plant operating in Europe. o No air emissions. o Applicable to wastes containing a wide range of contaminants. o Acceptable reductions of hydrocarbon, metal, and salt content in the produced solids are expected.	o Treatment costs high if waste contains large fraction of fine particles. o Technology not commercially available in North America. o Contaminant levels in residual solids will have to be determined by pilot testing.

Table 7.3 Aqueous Extraction and Leaching Technologies (concluded)

TECHNOLOGY	ADVANTAGES	DISADVANTAGES
Hot Water Extraction		
This process, developed by Dr. C.A. Clark, is used for the extraction of bitumen from tar sands at both Suncor's and Syncrude's operating plants in Alberta.	o Demonstrated on a commercial basis for extraction of bitumen from tar sands. o Extensive experience with process. o Process components relatively simple.	o Presence of fine clays in waste makes separation of the water and solids difficult. o Requires large volumes of water. o Contaminant levels in residual solids will have to be determined by pilot testing.
RTR/Gulf Process		
This process was developed by RTR Oil Sands (Alberta) Ltd. and Gulf Canada for the removal of hydrocarbons from clay-based sludges. The technology is based on chemical addition and centrifugation to achieve phase separation.	o Process is flexible with respect to feedstocks being treated. o Process is relatively simple.	o Separated solids probably need further treatment prior to disposal. o Not demonstrated on a commercial basis. o Process may not remove/reduce heavy metals and inorganic contaminants. o Some of the chemical additives may themselves be hazardous.

Table 7.4 Thermal Treatment Technologies

TECHNOLOGIES	ADVANTAGES	DISADVANTAGES
Rotary Kiln Incinerator The incinerator is a refractory-lined horizontal cylinder that is fed at one end with waste and discharges ash at the other end.	o Commercially available and well established process. o Mobile units available. o Well accepted performance record. o Can accommodate a variety of waste types. o Can accept batch or continuous feed. o Relatively simple device - control of the feed and combustion are relatively easy.	o Potential lengthy siting/ permitting process because of air emissions. o Solid residues (ash, flue dust, etc.) may still be considered hazardous. o Potential high maintenance due to number of mechanical components. o If waste contains high salt content, can produce fine particulates which are difficult to remove. o Small-scale system may not be cost effective for this application.
High Temperature Slagging Incinerator (HTSI) Slagging kilns have the explicit intention to remove the ash as a liquid and to maintain a pool of slag at the discharge end of the kiln.	o Easy removal of ash in molten form. o Absorption of inorganics (salts) in the molten pool. o Can accommodate a variety of waste types. o Mobile units available.	o In the event of a sudden temperature drop, solidified slag forms within the kiln and prevents ash removal, resulting in a major shutdown for maintenance. o Higher temperatures generate higher levels of nitrogen oxide that result in higher maintenance requirements than for non-slagging kilns. o Technology has limited use in North America. o Expensive air emission control equipment is relied on to remove metal and salt. o Small-scale system would not be cost effective for this application.

Table 7.4 Thermal Treatment Technologies (continued)

TECHNOLOGIES	ADVANTAGES	DISADVANTAGES
Fluidized-Bed Incinerator		
The incinerator is a vertical, refractory-lined, steel structure containing a bed of inert granular sand-like material. The inert material, usually sand, is fluidized by the injection of air into the bottom of the bed. Once the bed is heated to the correct operating temperature for combustion, waste is injected into or above the bed. Supplementary fuel, to maintain combusion, is fed directly into the bed or above the bed.	o Simple, compact design; no moving parts in the combustion zone. o Excellent for wastes relatively uniform in size but difficult to pump or atomize. o Allows combustion of wastes with relatively low heating values without the use of auxiliary fuel once unit has been started and placed in operation.	o Only designed for continuous feeding. o Solid waste must be sized to be relatively uniform. o Poor fuel consumption at low levels. o Need to closely monitor constituents of the feed. Inorganics in the feed, particularly salts, may melt at bed temperatures or may generate molten eutectics in the bed, which will cause bed seizure and a loss of fluidization. o Small scale system would not be cost effective for this application.
Molten Salt Incinerator		
The incinerator is a refractory-lined vessel containing a bed of molten salt (sodium chloride, sodium sulphate, sodium carbonate, etc.) which is maintained at temperatures of 800 to 900°C. This unit is designed particularly for treatment of chlorinated hydrocarbon wastes. Chlorine in the waste reacts with salt to form a chloride, which can then be removed from the system.	o Particularly suited for treatment of chlorinated hydrocarbon wastes. o Can use low cost supplemental fuels. o Process emissions are inorganic salts, often nonhazardous and of low volume.	o Limited use in industry; process still in experimental stage. o Relatively much higher capital cost. o Poorly suited for wastes with high amounts of noncombustible ash. o Small-scale system may not be cost effective for this application. o Expensive air emission control equipment is relied on to remove metal and salt.
Infrared Incinerator		
The unit is basically a conveyor belt system passing through a long rectangular, refractory-lined chamber. Waste materials are subjected to high temperature radiation from electric heating elements in an atmosphere of nitrogen.	o Startup from cold condition relatively quick. o Some experience in industrial waste applications. o Low level of particulate emissions. o Demonstrated high destruction and removal efficiency on wastes contaminated with PCBs and other organic materials.	o Feed preparation and sizing critical with this system. o Electric power required for startup results in a large connected load. o Removal of metal and salt not well documented.

CG/CPA/989

Table 7.4 Thermal Treatment Technologies (concluded)

TECHNOLOGIES	ADVANTAGES	DISADVANTAGES
Taciuk Processor		
This rotary pyrolysis process is a combination of thermal treatment (to evaporate water and volatile organics) followed by thermal cracking (of heavier oils) along with the formation of coke and finally of combustion of the coke to provide heat for the process and to maximize the reduction in hazardous organic material.	o Technology is in advanced state of development. o Can process a wide range of waste types. o Can accommodate either fixed or movable plant. o Has been pilot-tested on petroleum production wastes.	o Process is relatively complex. o Requires licensed (thermal) operator. o Number of auxiliary systems required could result in high maintenance. o Small-scale system may not be cost effective for this application. o Expensive air emission control equipment is relied on to remove metal and salt.
Electric Pyrolyzer		
Process takes place in an oxygen-deficient reactor and uses electrical energy to heat and dissociate the waste feed through a combination of thermal cracking and condensation reactions into gaseous, liquid, and solid fractions.	o Can accommodate either fixed or mobile applications. o Can process a wide range of waste types.	o Process still in developmental stage. o No experience with petroleum production wastes. o Expensive air emission control equipment is relied on to remove metal and salt.

CG/CPA/989

Table 7.5 Biodegradation Treatment Technologies

TECHNOLOGY	ADVANTAGES	DISADVANTAGES
Soil Slurry Biodegradation		
Oil sludges and solids are placed in a large tank with water, oxygen, and nutrients. This conglomeration is thoroughly mixed, creating a soil slurry. As the mixing is occurring, biological degradation is taking place, converting organics into carbon dioxide, water, and biomass.	o It works better than in situ biological treatment because there is more contact with the nutrients and oxygen, thus more complete reactions. o Since the process takes place in a tank, year-round operation is possible despite seasonal weather conditions. o Can process a wide range of waste types.	o Very large tanks are required, thus making mobile units difficult. o Very low removal efficiencies for inorganic compounds. o May result in air emissions that require control and treatment. o Requires fresh water to operate. o Reaction is slow and requires several weeks to treat each batch of waste.
Landfarming/Land Treatment		
Landfarming involves controlled spreading of biodegradable waste on soil so that biodegradation can break down or immobilize contaminants. Organics, nutrients, metals, and other elements of the sludge must be applied at rates which are consistent with soil and crop utilization and fertility.	o Provides treatment as well as disposal in one step. o Costs are generally attractive. o May improve soil structure and fertility. o Well-proven, demonstrated low technology process for handling hydrocarbon-contaminated wastes with low levels of heavy metals and/or salt. o Can be used in combination with other high technology processes for disposal of final solid residues/solids.	o Can only apply during several months per year in the Canadian climate. Cold temperatures also decrease treatment efficiency. o Potential for groundwater and surface runoff contamination if facilities not engineered properly. o Odours and aesthetics are concerns. o Can require large areas of land. Sites have a limited life due to hazardous substance accumulation. o Siting and permitting can be lengthy and complex processes. o Land management monitoring and analysis can become very complex and costly. o Can be exposed to long-term liability and costly remediation as a result of poor operation. o Wastes with high metal and salt content would either require an enormous amount of land or extensive runoff and leachate collection/disposal systems.

Table 7.5 Biodegradation Treatment Technologies (concluded)

TECHNOLOGY	ADVANTAGES	DISADVANTAGES
Composting Composting involves aerobic thermophilic decomposition of organic matter by microorganisms. Using the static pile method, the material to be composted is placed in piles and kept aerated by aeration headers buried under the pile. In the windrow process, the piles are placed in rows and are periodically turned by heavy machinery. In the mechanical in-vessel composting process, the process takes place in an enclosed vessel where conditions are closely controlled.	o Relatively simple to operate. o Product is useful as a soil conditioner.	o Requires long treatment time. o Canadian climate will necessitate the in-vessel process and very large tanks. o Process does not remove salts. o Process is well developed for stabilizing municipal wastewater sludges but not oilfield-type waste.

Table 7.6 In Situ Treatment Technologies

TECHNOLOGY	ADVANTAGES	DISADVANTAGES
Radio Frequency Heating		
This process uses radio frequency emitted by electrodes inserted into the waste to heat the soil to volatilize the organics. The vapours are vented to a surface vapour barrier, condensed, and disposed of. RF heating is developed by IIT Research, Chicago.	o Process minimizes contaminant release during remediation. o Can accommodate fixed or mobile applications.	o Process is currently at the research and development stage with ongoing field testing. o Potential off-gas emissions. o Non-uniform heating may occur. o Metals and salts are not destroyed by this process.
Vitrification		
Battelle Inc. developed a process which melts the waste into a solid vitrified mass using high electrical current passing through electrodes and a graphite and glass frit matrix. Off-gases migrate to the surface to be collected by a hood, and are directed to an off-gas treatment system.	o Inorganics are physically and chemically trapped in a solid mass. o Organics are destroyed or volatized from the molten soil. o Final waste form has long-term stability and durability. o Applicable to a variety of different waste types. o Minimum contaminant release during remediation compared to chemical in situ treatment. o Can accommodate fixed or mobile applications.	o Extremely high power requirements. o Treatment is unproven for full-scale remediation. o Total destruction of the original soil characteristics. o Potential off-gas emissions. o Potentially a high cost alternative.
Solidification/Fixation		
This process uses chemical treatment to limit the solubility of the contaminants in the soil and then uses solidification to capture the waste in a solid block or uses encapsulation to surround the waste with a liner.	o Extensive experience and commercially available. o Costs are generally below that of incineration. o Can be used in combination with other high technology processes to dispose of final solid residues.	o Potential increase in disposal volume due to addition of solidification agents. o Thorough laboratory analysis to establish waste compatibility with chemical or solidifier is required. o Potential air emissions during tilling. o Limited to wastes containing less than 20 percent organics.

Table 7.6 In Situ Treatment Technologies (concluded)

TECHNOLOGY	ADVANTAGES	DISADVANTAGES
Biological Treatment		
This process uses microorganisms to metabolize and decompose organic compounds. Water, oxygen, and nutrients are added to accelerate the reaction.	o Simple process. o Costs are generally attractive. o Conventional agricultural equipment can be used. o Proven, well demonstrated process can be used in combination with other high technology processes to handle final aqueous phase wastes.	o Process not well established for oilfield-type wastes in cold climates. o Can only be applied for a few months per year in the Canadian climate. Cold temperatures also decrease treatment efficiency. o Treatment time of weeks to months may be required. o Potential air emissions during operation.

Table 7.7 Other Treatment Technologies

TECHNOLOGY	ADVANTAGES	DISADVANTAGES
Industrial Landfill		
The type of waste considered in this study would be disposed of in a Class 1 industrial landfill and would require two liners, a leachate collection and disposal system, a leakage detection system between the two liners, surface run-on and run-off control systems, a gas interception and venting system, and a groundwater monitoring system.	o Simple process. o Generally cost attractive initially. o Well suited for final burial of pretreated waste material. o Can be engineered to handle various types of wastes. o Proven and well developed low technology option suitable for many of the wastes considered in this study. o Can be used in combination with other high technology processes to handle final solid residues.	o Potentially high operating cost alternative. o Long-term liability remains. o Regulatory approval may be difficult to obtain. o Monitoring, testing, and operating likely to be required many years after site closure. o Removal of waste after closure may be required if the site is not compatible with proposed land use.
Hot-Mix Asphalt		
Contaminated soils are recycled into hot-mix asphalt. During the process, which mixes virgin aggregate and 5 percent contaminated soil together, water and hydrocarbon are flashed off and incinerated in the burner.	o A full-scale plant has demonstrated this treatment technology with success. o Cost effective with other treatment technologies. o Can be used in combination with other high technology processes to handle final solid residues.	o Feedstock is limited to a very narrow range. o Potential air emissions if not controlled. o Operation dependent on HMA demand. o Quality control and marketing of product HMA is required.
Aglofloat Process		
Alberta Research Council has developed a process in which finely crushed coal and hydrocarbon-contaminated material is mixed in a slurry and is later formed into agglomerates to be used to fuel coal-fired burners. The clay and sand are left in the slurry and later treated in settling tanks.	o No air or liquid emissions. o Mobile plant possible. o Potentially a low cost alternative. o Can be used in combination with other high technology processes to handle final solid residues.	o Limited pilot testing on oily sludge and sand. o Coal is required as co-feed. o Quality control and marketing of product coal are required.

Table 7.7 Other Treatment Technologies (concluded)

TECHNOLOGY	ADVANTAGES	DISADVANTAGES
Colt Treater The Colt Treater is a distillation system where treater and separator interface material is fed to the treater and the water and lighter hydrocarbons present are vapourized. The dry oil is pumped to storage. The distillate vapours, water, and hydrocarbon exit the treater and are recondensed. The condensed fluid is separated into water, condensate, and noncondensable vapours. The water portion is pumped to disposal, the noncondensables are vented, and the condensate hydrocarbon liquid is recycled to the sales stream.	o Proven process in treating treater and separator interface pads. o Equipment available commercially. o Process may be adaptable to handle other similar wastes.	o Process not capable of treating full range of waste sludge and solids considered in this study.
Oleophilic Sieve The Oleophilic Sieve is an apertured oleophilic endless process belt supported by conveyor rollers to form a straight horizontal top flight and a bottom flight that hangs down in the form of a catenary in the mixture it is separating. Taking advantage of buoyancy and oleophilic adhesion, oil in the mixture attaches to the bottom flight and is conveyed to the top flight where heat is used to help remove oil from the belt into a receptacle under the top flight.	o Low energy requirements expected. o No air emissions; thus no off-gas treatment required. o Compact design. o Can be used as an effective pretreatment step in combination with other high technology options.	o Pilot testing of tank bottom and separator oily sludges has failed to achieve separation.
Gravity Separation Waste reclaimers often use crude physical separation processes for oil, water, and solids separation. The most common method used is heating oily waste in a steel or concrete pit to 93°C to recover as much free oil as possible. The produced water is deep well injected. The remaining solids are either mixed with clay and landfilled or mixed with lime or fertilizer and landfarmed.	o Simple process; operators require minimal training. o Relatively low initial cost in comparison with other treatment technologies. o An established network of ERCB-approved reclaimers that utilize this technology. o Can be used as an effective pretreatment step in combination with other high technology options.	o Aqueous and solid phases after separation may still need treatment prior to disposal. o May not be able to separate find solids effectively. o Process is restricted to batch basis if there is variability in feed characteristics.

8. ASSESSMENT OF TREATMENT PROCESSES

8.1 APPROACH

In this study, two schemes of treatment plant configuration are considered:

1. A small/local plant that serves batteries within an operating field with one or more operating companies. It is expected that this facility would receive wastes within a narrower feed range and, therefore, may be more suitable to simpler, low technology options or simpler variations of a high technology process.
2. A large/central plant that serves a region of many batteries and operating companies. The wastes received at a central facility exhibit a wide range of characteristics and such a treatment facility would most likely involve either a developing high technology process or a combination of emerging high technology processes and existing low technology methods.

The major types of wastes within the scope of this study were identified in Section 3. The wastes that need to be handled in either scheme can exhibit the following range of characteristics:

1. Oil: varies from low of 4 to 6 percent to high of 50+ percent
2. Water: varies from low of 4 percent to high of 70 percent
3. Solids: varies from low of 10 percent to high of 85+ percent
4. pH: varies from low of 4.8 to high of 12.5
5. Particle Size: ranges from fine material of 2 microns to coarse sand of 2-mm diameter with a significant portion of wastes having an average size of less than or equal to 60 microns
6. Heavy Metals: present in varying amounts
7. Salts: present in varying amounts, being primarily calcium, magnesium, and sodium chlorides.

Potential treatment technologies would, either on their own or in combination with other processes, have to be capable of treating wastes having a significant portion of fine particles (silty, clay material); separating oil/water from solids; dewatering and desalting solids; and removing or immobilizing metals in solids.

Technical evaluation criteria by which the treatment processes have been assessed were developed by CH2M HILL in conjunction with the project technical steering committee and reviewed by the membership of the CPA Environmental Research Advisory Council (ERAC). The evaluation is divided into two steps: a preliminary screening step and a detailed evaluation step.

8.2 PRELIMINARY SCREENING

In the preliminary screening of treatment processes, each of the processes described in Section 7 is evaluated against a set of criteria. These criteria must be satisfied completely in order for the technology to be considered further.

The preliminary screening criteria are:

1. The treatment process must have successfully been demonstrated at pilot scale to have the capability to treat at least one of the waste types identified in Section 3 of this report.
2. As outlined in Section 3.12, this study focuses on the treatment and/or disposal of waste having a significant proportion of fine particles (silty clay materials). Therefore, the treatment process must have the capability to treat fines of down to 2-micron diameter efficiently.

Each treatment process described in Section 7 was evaluated against the above preliminary screening criteria. The shortlist is presented in Table 8.1.

Justifications for eliminating other processes are as follows:

Table 8.1 Shortlist of Treatment Processes After Preliminary Screening

Solvent Extraction Treatment	Aqueous Extraction/ Leaching	Thermal Treatment
CF Systems Extraction	U.S. EPA Mobile Soil Washer	Rotary Kiln
B.E.S.T.	RTR/Gulf Sludge Conditioning	Taciuk Processor
Hot Toluene Fluid Extraction		
BP Oil Solvent Extraction		

Biodegradation Treatment	In Situ Treatment	Other Treatment/ Disposal Processes
Soil Slurry Biodegradation	Solidification/ Fixation	Industrial Landfill
Landfarming	Biological	Aglofloat
		Colt Treater
		Oleophilic^{R} Sieve

Process	Justification for Elimination
HWZ Soil Washing	Not applicable or inefficient in treating fines
Heidemij Soil Washing	" " "
Oil CREP	" " "
Harbauer Soil Washing	" " "
MTA Soil Washing	" " "
Hot Water Extraction	" " "
Gravity Separation	" " "
Infrared Incineration	Insufficient demonstrated success in treating at least one of the waste types considered in this study
Molten Salt Incineration	" " "
Fluidized Bed Incineration	" " "
High Temperature Slagging Incineration	" " "
Electric Pyrolyzer	" " "
Vitrification	" " "
Radio Frequency Treatment	" " "
Hot-Mix Asphalt Process	" " "

8.3 DETAILED EVALUATION

Those processes that passed the preliminary screening were evaluated against the following desirable criteria:

1. Operability - The operability criterion relates to the reliability, simplicity, and stability of a system. Relatively simple systems with high service factors (low downtime), minimal pretreatment, and low operating and maintenance requirements that are easy to control are considered most desirable.

2. Performance - A system's performance is its ability to treat the waste with high recovery/destruction/removal efficiencies and good turndown capability while yielding a product that meets or exceeds the outlet quality requirements by a reasonable margin of safety and a residue that is low in volume and readily disposed of in an acceptable manner.
3. Portability - A mobile unit is the most portable. Skid-mounted units are more transportable than fixed plants.
4. Potential for commercialization - Those technologies with the least anticipated scale-up problems and the least need for additional pilot testing have the highest potential for commercialization.
5. Flexibility of process to handle varying feed - Those technologies that have demonstrated the flexibility to handle a wide range of feed characteristics (i.e., particle size, oil/water/solids composition) are considered most desirable.
6. Field experience in similar applications - Those technologies that have demonstrated actual field experience with similar waste types and environmental conditions are most desirable.
7. Expandability - Module-type construction using existing, well proven pieces of equipment are least expensive to expand.
8. Technology builds on or enhances current practices - Technologies that are similiar to current oilfield practices (e.g., physical and chemical/thermal enhanced separation) are easier to adopt by existing operating and maintenance staff.
9. Operational safety risk - Technologies operating in low temperature, low pressure environments using nontoxic substances have a lower safety risk to operators than technologies operating in high temperature, high pressure environments using toxic substances.

10. Relative cost - In general, physical treatment processes cost less than physical/chemical or biological processes; physical/chemical or biological processes cost less than thermal treatment processes.

As some criteria were considered to be of greater or lesser importance than others, weighting is assigned to each by CH2M HILL with input from the project technical steering committee as shown below. The more important the criterion, the higher the weighting.

Detailed Evaluation Criteria	Small/Local Plant Weighting Factors	Large/Central Plant Weighting Factors
Operability	140	100
Performance	130	140
Portability	100	50
Potential for commercialization	50	120
Flexibility of process to handle varying feed	120	130
Field experience in similar applications	100	100
Expandability	50	90
Technology builds on or enhances current practice	90	50
Operational safety risk	110	80
Relative cost	110	140

Each process was evaluated relative to the others and assigned a score of 1 to 10 (with 10 being the score given the best-fitting process) under each of the criteria. The product of the weighting times the score gives a weighted score for each criterion. The sum of these for all criteria then gives a total weighted SCORE for each alternative, with the highest total SCORE theoretically assigned to the process that best satisfies the detailed evaluation criteria. The maximum possible score is 10,000. It is important to recognize that the scoring is done purely on a relative basis for the case being examined. A detailed evaluation worksheet is presented in Appendix C.

The results of the detailed evaluation for a small-scale local plant are presented below.

Process	Small Plant Score
1. BP Oil Solvent Extraction	6510
2. B.E.S.T.	6460
3. U.S. EPA Soil Washer	6380
4. CF Systems Extraction	6370
5. Hot Toluene Fiuid Extraction	5610
6. RTR/Gulf Sludge Conditioning	5550
7. Taciuk Processor	5360
8. Industrial Landfill	5000
9. Landfarming	4720
10. Oleophilic Sieve	4710
11. Aglofloat	4660
12. Rotary Kiln	4540
13. Colt Treater	4110
14. Soil Slurry Biodegradation	3700
15. In Situ Biological Treatment	3630
16. Solidification/Fixation	2930

The results of the detailed evaluation for a large regional plant are presented below.

Process	Large Plant Score
1. B.E.S.T.	6980
2. BP Oil Solvent Extraction	6970
3. CF Systems Extraction	6870
4. U.S. EPA Soil Washer	6550
5. Taciuk Processor	6050
6. Hot Toluene Fluid Extraction	5640
7. Rotary Kiln	5410
8. RTR/Gulf Sludge Conditioning	5340
9. Industrial Landfill	5300
10. Landfarming	5020

Process	Large Plant Score
11. Aglofloat	4950
12. Oleophilic Sieve	4780
13. Colt Treater	4410
14. Soil Slurry Biodegradation	4030
15. In Situ Biological Treatment	3970
16. Solidification/Fixation	3230

8.4 GENERAL DISCUSSION

The various components of a treatment system have to perform specific functions such as oil removal, dewatering, and immobilization of salt and metals. Few processes exist that would perform all of these functions cost effectively. In situ solidification/fixation, in situ biological treatment, and soil slurry biodegradation consistently rank lower in relation to other processes for criteria such as operability, performance, flexibility to handle varying feeds, and similar field experience. Also, these processes are very different from current practices and would require significant adjustment of the technical skills possessed by typical oilfield operators. Although thermal treatment processes such as pyrolysis and incineration scored relatively high on performance, potential for commercialization, and flexibility to handle varying feed criteria, they typically require external auxiliary systems such as feed preparation, air pollution control, wastewater treatment, etc., that add a significant complexity and overall cost to the basic process. They are also significantly different from current practices. Landfilling and landfarming used to be relatively simple and inexpensive to set up. Recent regulations are making the process more difficult and complicated. To apply these processes would require either numerous small operations over a wide area or extensive transportation of potentially hazardous materials. Also, the requirements for monitoring and testing before and after site closure would likely result in high operating costs. Since the contaminants are

neither destroyed nor recovered, long-term liability remains. Other processes such as the hot toluene fluid extraction, RTR/Gulf sludge conditioning, Oleophilic Sieve, Aglofloat, and Colt Treater are either in a very early stage of development or limited to a very narrow range of feed application. Aglofloat also requires coal as a co-feed.

8.5 SMALL-SCALE LOCAL PLANT TECHNOLOGY EVALUATION

The top four processes for a small-scale local plant are:

1. BP Oil Solvent Extraction
2. B.E.S.T.
3. U.S. EPA Soil Washer
4. CF Systems Extraction

All four processes scored over 6,000 points in the evaluation and the spread between the first- and fourth-rated process is less than 3 percent. The fifth-rated process scored substantially lower than these four. Of the four processes, three (BP Oil Solvent Extraction, B.E.S.T., and CF Systems Extraction) are solvent extraction technology while the fourth (U.S. EPA Soil Washer) is an aqueous extraction/ leaching technology. All four processes have demonstrated experience treating similar types of waste and were assessed to be able to handle fine material adequately. The two processes (BP Oil and CF Systems) that use propane as a solvent basically apply the conventional oilfield practice of adding diluent to maximize hydrocarbon recovery. All four processes generate a residual solids fraction which must be disposed of. This is an example where an existing low technology option, such as landfill, landfarming, etc., can be used in combination with an emerging high technology process to provide a suitable treatment system. Although the level of contamination of salt, organics, and heavy metals in the residual solids is expected to be at acceptable levels for disposal, pilot and/or bench-scale testing on actual waste material would have to be carried out to confirm this.

8.6 LARGE REGIONAL PLANT TECHNOLOGY EVALUATION

In the evaluation of processes for the large regional plant concept, the top five rated processes, all scoring over 6,000 points, are:

1. B.E.S.T.
2. BP Oil Solvent Extraction
3. CF Systems Extraction
4. U.S. EPA Soil Washer
5. Taciuk Processor

In this evaluation, the difference between the first- and fifth-rated process is approximately 15 percent.

The top three rated processes are all based on solvent extraction technology, while the fourth and fifth processes are based on aqueous extraction/leaching technology and thermal treatment technology, respectively. From the technology evaluation, it is apparent that thermal treatment technology such as the Taciuk Processor is more attractive at the large regional plant scale than at the small local plant scale. As previously mentioned, the solvent-technology-based processes are expected to be able to handle fine materials and generate a residual solids fraction which meets disposal requirements. Again, existing low technology disposal options, such as landfill, landfarming, etc., can be used to provide a suitable means of final residual solids disposal. This would have to be confirmed in future bench-scale or pilot-scale testing with the actual waste materials.

8.7 TREATMENT COSTS

Preliminary cost information was obtained from the literature and from discussions with process vendors for the top-rated processes. Cost information was not available for the BP Oil Solvent Extraction process due to the vendor's confidentiality requirements.

The treatment costs presented on Table 8.2 are based on a wide range of plant capacities and range from as small as 1 tonne/day for the U.S. EPA Soil Washer to as large as 384 tonnes/day for the Taciuk Processor. In generating treatment costs, some processes include major cost items such as site development, field construction, utilities, licences/permits, etc., while others do not. Also the specific factors for calculating the annualized capital cost portion of

Table 8.2 Treatment Costs

	B.E.S.T.	BP Oil	U.S. EPA Soil Washer	CF Systems	Taciuk Processor
Treatment Cost - $CDN/tonne (Blended capital and operating)	65-132	N/A	300-545	180-480	75-85
Plant Capacity Basis	91 t/d		1 t/d	35 t/d	384 t/d
Qualifications Re: Cost	Not included are: - Residue disposal - Permits - Utilities - Sampling/ analysis - Taxes/licences - Transportation - Field construction - Site development		Not included are: - Site development - Residue disposal - Utilities - Sampling/ analysis - Insurance/ taxes - Licences/ permits	Not included are: - Residue disposal - Utilities - Site development	Not included are: - Residue disposal
Comments		Cost info. not available due to vendor's confidentiality reguirement.			

$75/t for single site setup

$85/t for mobile unit

9. CONCLUSIONS

CPA and Environment Canada have embarked upon a study of the treatment technology available for treating and disposing of various hydrocarbon-, metal-, and salt-contaminated solids. Phase I is a global assessment of existing and developing processes/technologies for handling wastes containing a wide range of contaminants and exhibiting a wide range of characteristics. The conclusions of the assessment are:

1. Existing waste treatment/disposal methods used by the oil industry are generally adequate for some of the waste streams considered in this study. The Phase I assessment has shown that emerging high technology processes will be required to handle the entire range of wastes contaminated with oil, salt, and heavy metals and with a significant fraction of fine material of less than 60 mircons.
2. While existing oil reclaimers are equipped to handle easy to separate oil/waste/solid wastes, they do not have technology in place to treat finer particle waste sludges/solids contaminated with high levels of salt and heavy metals. Oil reclaimers could be re-equipped with new technologies/processes demonstrated in subsequent phases of this project and serve as regional treatment centres for the oil industry.
3. New environmental legislation such as the Canadian Environmental Protection Act (CEPA) and future amendments to existing legislation and regulations are focusing on establishing more tailored criteria with minimum standards and procedures, and taking on a more cradle-to-grave approach for waste management. These changes will have a direct effect on the way oilfield production wastes are managed in the future.
4. A number of organizations are actively promoting new technology/processes for treatment of oil production wastes. Most of them have very little operating history

on wastes of this type and require answers to questions regarding operability, process performance, pretreatment requirements, cost, etc.

A total of 32 potential treatment processes were reviewed and reduced to 16 processes by evaluating each process against preliminary screening criteria. The remaining 16 processes were then evaluated against 10 desirable criteria which were developed by CH2M HILL in conjunction with the project technical steering committee and reviewed by the membership of the CPA Environmental Research Advisory Council.

In the small-scale local plant scenario, four processes clearly scored higher than the rest. The top two rated processes (BP Oil and B.E.S.T.) are both solvent extraction based technologies. These two processes are similar to current oilfield production processes in some respects and have field-demonstrated experience in treating similar wastes. Although the top-rated processes are all emerging high technology solutions, there will most likely be a need to combine these with an existing low technology disposal process/method, such as landfill, landfarm, solidification/fixation, etc., to provide a solution for final residual solids disposal.

In the large-scale centralized plant scenario, five processes clearly scored higher than the rest. In the five are processes based on solvent extraction technology (B.E.S.T., BP Oil, CF Systems); aqueous extraction/leaching technology (U.S. EPA Soil Washer); and thermal treatment technology (Taciuk Processor). Thermal treatment technology (Taciuk Processor) becomes more attractive in the large plant scenario where a much larger volume of waste material is being handled.

Again, these emerging high-technology-based processes will most likely have to be used in combination with existing low technology disposal methods to provide a solution for final residual solids disposal.

10. RECOMMENDATIONS

The technology assessment presented in Section 8 resulted in the identification of certain classes of generic treatment technologies such as solvent extraction and aqueous leaching/extraction as being likely candidates for future consideration. Vendor-supplied solvent extraction processes such as B.E.S.T., BP Oil, and CF Systems have potential application for treatment of wastes described in Section 8. Aqueous leaching/extraction technology may also be applicable in treating these wastes and within this generic technology class, the U.S. EPA Soil Washer is a good example of the type of process that may be adaptable.

The overall scope of subsequent phases of this study will include the following:

1. An initial scope-focusing/criteria-setting phase to gather additional information regarding the characteristics of the various wastes and to develop waste treatment criteria/strategies, taking into consideration priority of wastes and corresponding low and high technology solutions
2. Detailed evaluation/assessment of the most applicable technology/process options, including bench/laboratory-scale testing
3. Demonstration of selected technology/process systems on a field pilot-scale level

The objectives of the next phases will be to provide:

1. Engineering and economic data, operational procedures, and expected treatment efficiencies in sufficient detail to allow participant member companies to determine the viability of treatment processes and the scale of commercial or individual treatment facilities most suitable to their needs
2. Final recommendations and guidelines for necessary follow-up work

It is recommended that the next phase of the study proceed based on a staged approach with at least two stages.

Stage 1 - The work in this scope-focusing/criteria-setting stage will be the further refinement of the waste characterization information and a more detailed assessment/evaluation of the low and high technology methods identified in this report. Characterization of wastes will be carried out to provide additional information as it applies to engineering/physical data and treatment requirements. To enable a more detailed assessment/evaluation of selected technologies, some preliminary laboratory/bench-scale testing will be carried out to obtain engineering and cost data, and discussions will be initiated with vendors of specific treatment systems and with reclaimers planning on making changes to existing facilities.

Stage 2 - The work in the second stage will be additional bench-scale testing to define process variables and further refine costs for selected technologies and processes and field pilot testing of the most promising technologies. It is recommended that this stage of the program be flexible enough to accommodate findings of other ongoing CPA/Environment Canada petroleum industry waste studies.

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Appendix A
WASTE CHARACTERIZATION INFORMATION

A.1 Waste Characterictics Summary
A.2 Waste Information Questionnaire
A.3 Waste Characterization Information Obtained from Respondants

TABLE A.1 WASTE CHARACTERISTICS - SUMMARY

WASTE TYPE	OIL CONTENT (%)	WATER CONTENT (%)	SOLIDS CONTENT (%)	pH (unit)	PARTICLE SIZE RANGE (microns)	CHROMIUM (mg/L)	LEAD (mg/L)	NICKEL (mg/L)	VANADIUM (mg/L)	CALCIUM (mg/L)	CHLORIDE (mg/L)	MAGNESIUM (mg/L)	SODIUM (mg/L)
Storage Tank Bottom Sludge	10 -25	45 -70	25 - 35	NR	2 - 2000	.1 - 120	.1 - 385	.46 - 125	.5 - 223	NR	NR	NR	NR
Waste Holding Pond/Pit - oily sludge	15 - 41	14 - 38	43 - 64	11.8	2% Gravel(2 - 60mm) 31% Sand(.06 - 2mm) 40% Silt(.002 - .06mm) 25% Clay(<.002mm)	20 - 21	41 - 65	40 - 75	50 - 123	4000 - 75000	21915 - 22021	144 - 5160	7866 - 10120
- oily solids	4 - 6	9 - 17	78 - 85	4.0 - 11.9	2% Gravel(2 - 60mm) 33% Sand(.06 - 2mm) 42% Silt(.002 - .06mm) 20% Clay(<.002mm)	14 - 43	7 - 44	0 - 35	21 - 38	142 - 51900	401 - 11005	5 - 9910	294 - 2967
Emergency Storage Pit Sludge	15 - 38	13 - 38	37 - 67	NR	Varies	.4 - .9	4 - 12	.6 - 5.1	1.7 - 3.5	8950 - 12000	NR	768 - 1200	446 - 500
Flare Pit - Sludge	33.1	Similar to waste holding pit sludge above		7.5	Similar to waste holding pit sludge above	18.9	260	22	26.7	156000	20922	72300	10000
- Solids	8.9	Similar to waste holding pit solids above		7.1	Similar to waste holding pit solids above	11.3	20	13	15.8	73600	20872	39600	11300
Treater Interface Pad (2.)	40 - 90	10 - 60	.5 - 5	NR	Fine	NR	NR	NR	NR	NR	NR	NR	NR
Slop Tank Interface Pad (2.)	40 - 90	10 - 60	.5 - 5	NR	Fine	NR	NR	NR	NR	NR	NR	NR	NR
Field Tank Sand (1.)	1.0 - 47	11.4 - 60	10 - 86	6 - 7	2 - 2000	.6 - 1.5	6.1 - 17.1	0 - [illegible]	3 - 10.7	320 - 44000	2950 - 10100	193 - 17000	1200 - 9400
Nabesna FWKO Desand Sludge (1.)	36	54	9	NR	2 - 60	NR	NR	NR	NR	NR	NR	NR	NR
Treater Desand Sludge (1.)	10 - 26	21 - 76	10 - 54	7.5	2 - 2000	5.4	28	1.4 - 24.1	9.5 - 37	975 - 12000	900 - 9400	155 - 1210	975 - 3700
Wolf Lake Slop Oil/Sludge (1.)	40	46	14	7.0	NR	4.8	46	12.8	13.1	9500	430	903	1340
Ecology Pit Mixture (1.)	4 - 55	4 - 66	25 - 79	7 - 12.5	2 - 2000	.6 - 130	0 - 840	10.5	10.2	2100 - 4630	625 - 7200	755 - 1790	383 - 4030

NOTES:
1. Heavy oil production waste.
2. This is not necessarily a waste. It is primarily composed of waxes and asphaltenes. Most operators recycle this material back to process.
3. NR denotes no data available.

TABLE A.2 CPA/ERAC SALT/HYDROCARBON/METAL CONTAMINATED WASTE STUDY - INFORMATION REQUEST

Plant/Field Site Name: Location:

Plant Type: Year Built:

Type Of Waste in Holding Facility	Estimated Quantity, Composition, & Percent of Total Volume	Location of Waste (tank, pit etc.)	Current Disposal Practice	Disposal/Reclamation Technologies Tried/Evaluated
Tank Bottom Sludges				
Wastewater Holding Pond Sludges				
In-field Treater Wastes				
Separator Wastes				
Waste Oil Storage Pond Sediments				
Heavy Oil & In-situ Oil Sand Sludges/Sands				
Combine Hydrocarbon & Brine Spilled Clean-up Material				

Please attach extra sheets if necessary and return completed forms to:

CH2M HILL Engineering Ltd.
11th Floor, 815 - 8 Avenue S.W.
Calgary, Alberta, Canada
T2P 3P2

Attention: Henry Yau

Table A.3.1
CONVENTIONAL OIL PRODUCTION
STORAGE TANK BOTTOM SLUDGE - MAJOR ION AND METAL CONTENT (1.)

PARAMETER	CONCENTRATION
Specific Gravity	.93 - 1.05
% Oil	43
% Moisture	38
% Solids	19
Arsenic	.003 - 53
Cadmium	0 - 16
Chromium	.1 - 126
Colbalt	3.8 - 37
Copper	.7 - 500
Iron	1270 - 34000
Lead	.1 - 385
Manganese	11 - 1610
Mercury	0 - 26
Molybdenum	.3 - 95
Nickel	.46 - 125
Selenium	0 - 53
Silver	.03 - 1.3
Vanadium	.5 - 223
Zinc	.1 - 825

NOTES:
1. All units in mg/kg (ppm) unless noted otherwise.

Source: PACE, November 1986.

Table A.3.2
CONVENTIONAL OIL PRODUCTION
WASTE HOLDING POND - MAJOR ION, METALS, AND ORGANIC COMPOUNDS (2.)

	AVERAGE OILY SLUDGE		AVERAGE OILY SOLIDS		AVERAGE POND BOTTOM EARTHEN MATERIAL	
PARAMETER	IN-SITU	LEACHATE(1.)	IN-SITU	LEACHATE(1.)	IN-SITU	LEACHATE
% Oil	15 -41		4 - 6			
- Salt (as NaCl)	1.5		1.6			
% Water	14 - 19		9 - 17			
% Solics	43 - 64		78 - 85			
- % Gravel	2		3			
- % Sand	31		33			
- % Silt	4		42			
- % Clay	25		20			
Aluminum	4370		6450		6250	
Antimony	0.3	<.05	0.3	<.05	0.15	<.05
Arsenic	8	<.05	10	<.05	9	<.05
Barium	598	0.79	543	0.31	839	2.22
Berylium	<.5	<.001	<.5	<.001	<.5	<.011
Boron	34		<5		21	
Cadmium	<.4	<.003	<.4	<.003	<.4	<.003
Calcium	75000		51900		24900	
Chromium	21	2.6	43	5.4	16	<.006
Colbalt	5	0.1	6	12	3.5	0.04
Copper	56.3		50	8.5	13.8	
Iron	16400		21000		10000	
Lead	65	<3	43.8	8.3	7.5	<.04
Magnesium	5160		9910		9160	
Manganese	559		431		401	
Mercury	0.07	0.03	0.06	<.05	0.11	<.05
Molybdenum	<1.3		2.5		1.5	
Nickel	75	53	35.4	42	5	0.09
Phosphorus	570		551		431	
Selenium	0.1	<.05	0.25	<.05	0.08	<.05
Silver	<25	<.2	<25	<.02	<25	<.02
Thallium		<.1		<.01		<.1
Titanium	34		143		178	
Vanadium	123	96	37.5	72	21.3	0.14
Zinc	373	3	498	98	60	0.34

Table A.3.2
CONVENTIONAL OIL PRODUCTION
WASTE HOLDING POND - MAJOR ION, METALS, AND ORGANIC COMPOUNDS (2.)

PARAMETER	AVERAGE OILY SLUDGE		AVERAGE OILY SOLIDS		AVERAGE POND BOTTOM EARTHEN MATERIAL	
	IN-SITU	LEACHATE(1.)	IN-SITU	LEACHATE(1.)	IN-SITU	LEACHATE
***** MAJOR ORGANIC COMPOUNDS (% by weight) *****						
Aliphatic			68			
Aromatics			17			
Asphaltene			14			
***** VOLATILE ORGANIC COMPOUNDS (ug/g) *****						
1,1 Dichloroethane			0.07			
Methylene Chloride			6.29			
Chloroform			0.37			
Benzene			101			
Trichloroethylene			0.15			
Toluene			42.4			
1,1,2 Trichloroethylene			8.72			
Tetrachloroethylene			0.18			
Chlorobenzene			0.28			
Ethylbenzene			19			

NOTES:
1. Contains a significant oil component.
2. All units in ug/g (ppm) unless noted otherwise.

Source: PanCanadian Petroleum Ltd., 1988.

Table A.3.3
CONVENTIONAL OIL PRODUCTION
WASTE HOLDING PIT SLUDGE/SOLIDS - MAJOR ION AND METAL CONTENT (1.)

	SLUDGE		CONTAMINATED SOILS	
PARAMETER	IN SITU	LEACHATE	IN SITU	LEACHATE
% Oil	15.5 - 18.5		1.5 - 6.9	
% Water	27.9 - 37.6		5 - 34	
% Solids	47 - 53.6		58 - 93	
Aluminum			.24 - .27	
Antimony		.0068 - .0089		.0002 - .0012
Arsenic		.0075 - .026		.0005 - .0047
Barium		.44 - .49		.12 - 1.22
Berylium		<.001		.001 - .14
Boron	5.04 - 8.77		.14 - 3.5	
Cadmium		.007 - .011		.001 - .01
Calcium	4080 - 4420		142 - 3340	
Chloride	21915 - 22021		401 - 11005	
Chromium		<.001		.001 - .006
Colbalt		<.001 - .007		.001 - .013
Copper		.001 - .002		.004 - .017
Iron		<.01		
Lead		<.01		<.01
Lithium	.34 - .36		.008 - .14	
Magnesium	144 - 206		5 - 107	
Manganese		.004 - .88	5.4	
Molybdenum		.01 - .049		<.001 - .043
Nickel		<.001		<.001
pH (unit)	11.8		4.8 - 11.9	
Potassium	974 - 1232		79 - 469	
Selenium		<.0002		<.0002
Silicon	29.4 - 44.4		7.1 - 57	
Silver		<.001		<.001 - .002
Sodium	7866 - 10120		294 - 2967	
Strontium	5.81 - 6.23		3.3 - 4.1	
Sulphate	140 - 160		55 - 325	
Thallium		0.001		.001
Vanadium		.006 - .042		.005 - .011
Zinc		<.001 - .004		<.001 - .095

NOTES:
1. All units in ug/g (ppm) unless noted otherwise.

Source: Gulf Canada Resources Ltd. (Stettler)

Table A.3.4
CONVENTIONAL OIL PRODUCTION
EMERGENCY STORAGE PIT SLUDGE - MAJOR ION AND METAL CONTENT (1.)

PARAMETER	SITE 1	SITE 5	SITE 6
% Oil	37.8	20.3	33.8
% Solids	36.7	66.8	43.2
% Moisture	25.5	12.9	22.9
Aluminum	25.7	9.1	8.5
Antimony	0.05	0.04	0.04
Arsenic	0.1	0.04	0.04
Barium	8.1	5.2	7
Beryllium	0.04	0.03	0.03
Boron	5.5	2	5.3
Cadmium	1.3	0.1	0.4
Calcium	12000	8950	9990
Chromium	0.41	0.9	0.9
Colbalt	0.66	0.6	0.6
Copper	1.2	0.9	0.8
Iron	<1.0	<1.0	<1.0
Lead	4	11.2	7.8
Lithium	3	3.4	2.1
Magnesium	944	1280	760
Manganese	2.43	8.5	3
Mercury	0.0572	0.654	0.0589
Molybdenum	3.7	0.1	1.8
Nickel	1.3	5.1	0.6
Phosphorus	<5	<5	<5
Potassium	570	327	235
Selenium	<.02	<.02	<.02
Silica	120	336	381
Sodium	446	570	580
Strontium	24.70	143.00	257.00
Thallium	<.1	<.1	<.1
Titanium	0.12	0.2	0.2
Vanadium	2.5	1.7	3.5
Zinc	3.08	110	44.5
Zirconium	0.2	0.2	0.5

NOTES:
1. All units in ug/g (ppm) unless noted otherwise.

Source: Mobil Oil Canada.

Table A.3.5
CONVENTIONAL OIL PRODUCTION
FLARE PIT SLUDGE/SOLIDS - MAJOR ION AND METAL CONTENT (1.)

PARAMETER	SLUDGE	SOLIDS
% Oil	33.1	8.9
Aluminum	13800	7490
Barium	550	145
Berylium	0.9	0.6
Boron	82	57
Cadmium	2.3	<.2
Calcium	156000	73600
Chloride	20922	28972
Chromium	18.9	11.3
Colbalt	8	8
Copper	62.7	27.9
Iron	21000	12700
Lead	260	20
Magnesium	72300	39900
Manganese	381	570
Molybdenum	<6	<6
Nickel	22	13
pH (unit)	7.5	7.1
Phosphorus	713	589
Potassium	3510	3080
Sodium	10000	11300
Sulphate	5529	2750
Vanadium	26.7	15.9
Zinc	6970	134

NOTES:
1. All units in ug/g (ppm) unless noted otherwise.

Source: Gulf Canada Resources Ltd.

Table A.3.6
CONVENTIONAL OIL PRODUCTION
INTERFACE PADS COMPOSITION

PARAMETER	TREATER INTERFACE PAD	SKIM TANK INTERFACE PAD
Loss on drying (@ 105 deg. C)	0.101	0.365
Analysis of dried sample:		
Total hydrocarbon	0.886	0.772
- wax	0.021	0.011
- asphaltene	0.314	0.182
Acid soluble material	0.066	
- iron	0.018	
- calcium	0.005	
- sulphide	ND	
Acid insoluble material	0.034	
Carbon & other organics	0.014	

NOTES:
1. All units mass fraction.

Source: PanCanadian Petroleum Ltd., November 1988.

Table A.3.7
HEAVY OIL PRODUCTION
LLOYDMINSTER WASTE

PARAMETER	COMPOSITE WASTE	SOLID FRACTION	OIL FRACTION
Oil (% W/W)	4 - 55		
Water (% W/W)	4 - 66		
Solids (% W/W)	25 - 76		
- Sand (%)	85		
- Silt (%)	11		
- Clay (%)	4		
Aluminum		14200	
Arsenic		4 - 18	
Barium		550	
Boron		33800	
Cadmium		1.5 - 40	
Calcium		18000 - 44000	
Chromium		6 - 370	
Colbalt		20 - 50	
Copper		60 - 160	
Iron		7000 - 40000	
Lead		0 - 840	
Magnesium		3000 - 17000	
Mercury		0 - .3	
Nickel		0 - 570	
pH (unit)	7 - 12.5		
Sodium		5600 - 9400	
Zinc		30 - 930	
Acids			.1 - 13
Aliphatics			28 - 39
Aromatics			11 - 23
Asphaltenes			5 - 19
Bases			.4 - 1
Neutral Nitrogens			12 - 25
Resins			9 - 25

NOTES:
1. All units in ug/g (ppm) unless noted otherwise.

Source: Sask-Alta Waste Disposal Co-operative, April 1983.

Table A.3.8
HEAVY OIL PRODUCTION
SASKATCHEWAN LLOYDMINSTER WASTE

PARAMETER	COMPOSITE WASTE
Oil (% W/W)	9 - 20
Water (% W/W)	6 - 20
Solids (% W/W)	65 - 84
Arsenic	0.75
Cadmium	0.5
Calcium	4200
Chloride	7280
Chromium	20
Colbalt	3.4
Copper	6.2
Iron	2230
Lead	9
Magnesium	1350
Mercury	0.05
Nickel	28
pH (unit)	7.4 - 8.1
Sodium	4030
Sulphide	41
Zinc	24

NOTES:
1. All units in ug/g (ppm) unless noted otherwise.

Source: Saskatchewan Energy and Mines

Table A.3.9
HEAVY OIL PRODUCTION
PALICAN LAKE SLUDGE (WABASCA FIELD)

PARAMETER	PIT SLUDGE
Oil (% W/W)	25 - 39
Water (% W/W)	21 - 36
Solids (% W/W)	26 - 54
Aluminum	1180
Barium	7.5
Berylium	<.1
Boron	25
Cadmium	<.3
Calcium	4630
Chromium	2.5
Copper	42.5
Iron	9420
Lead	30
Magnesium	1790
Manganese	88.8
Molybdenum	<6
Nickel	164
pH (unit)	8
Phosphorus	345
potassium	105
Sodium	393
Vanadium	18.8
Zinc	575

***** PARTICLE SIZE DISTRIBUTION *****

GRAIN SIZE (microns)	PERCENT BY WEIGHT
177+	9.0
88	0.5
44	10.7
22	14.2
11	11.4
5.5	11.2
<5.5	43.0

NOTES:
1. All units in ug/g (ppm) unless noted otherwise.

Source: Gulf Canada Resources Ltd.

Table A 3.10

OILFIELD WASTES TREATMENT TEST PROGRAM

WASTE CONSTITUENT ANALYSIS DATA

(sorted by type)

SOURCE NUMBER (see legend)	1	8	11	10	3	9	4	12	2	13	7	14	5	16	15	6
UNITAC SAMPLE NUMBER	8709-01	8708-03	8710-01	8708-01	8712-01/	29704-04/ -05/6/7	8704-01/ -02/03	8709-03/ -04	8709-02 8711-01	8710-02	8711-01	8713-02/ -03	8706-08	8702-01	8701-06	8708-02, 8709-1/2
CHEMEX LAB NUMBER	1816-10	1091-2	1816-7	1091-1	1816-6	1816-2	1816-5	1091-6	1816-9	1816-8	1816-3	1091-3	1816-4	1393-14	1393-4	1816-1
WASTE TYPE	FIELD TANK SAND				DESAND SLUDGES				DESAND SLUDGES			DESAND SLUDGES		HEAVY OIL		ALLOYD COMPOSITES
PROXIMATE ANALYSIS																
material density	1.56	0.89	1.18	1.18	0.97	1.54	0.84	1.05	0.98	1.29	0.97	0.73	0.98			1.24
wt % ash															70.6	
wt % oil	16.4	3	1.4	14.5	39.8	24.9	22.8	6.9	42.6	32.9	51.3	87	98.7	94.8	14.1	15.6
wt % water	17.1	4.6	11.4	14.9	46.3	22.6	39.2	18.6	42.6	25.4	33.4	9.05	10.1	0.6	5.82	15.3
wt % solids	65.8	91	88.8	68.5	14.8	51.4	38.4	71.4	14.6	43.4	12.8	1.44	-8.1	4.6	79.4	68.8
Elemental Content																
carbon (% by wt.)														86.5	12.4	
hydrogen (% by wt.)														10.8	2.2	
nitrogen (% by wt.)														0.3	0.8	
oxygen (% by wt.)																
sulphur (% by wt.)	0.86	0.18	0.15	0.69	2.38	1.51	1.64	0.32	1.95	1.68	3.81	2.33	4.63	2.1	0.6	0.87
Water Samples Only (ppm)																
oil and grease																
total suspended solids																
pH (units)	7.81		6.16	7.85	7.82	7.51	7.25	7.32	6.78	7.09		5.78	6.98		8.13	7.47
total organic carbon																
total inorganic carbon																
total carbon																
phenols																

LEGEND OF WASTE TYPES:

NO.	SOURCE & TYPE	FIELD	TYPE 0
1	SASKATCHEWAN TABLEFLAGS FIELD TANK SAND, 8709-01	1	1
2	COMPOSITE OF LLOYDMINSTER & LINDBERGH SLOP OIL SLUDGES, 8709-02,8711-01	3	2
3	WOLF LAKE SLOP OIL/SLUDGE, 8712-01/02	2	2
4	WOLF LAKE DESAND SLUDGE, 8704-01/02/03	2	2
5	WOLF LAKE HEAVY OIL, 8706-08	2	4
6	LLOYDMINSTER COMPOSITE, 8708-02,8709-01/02	3	5
7	LINDBERGH DESAND SLUDGE, 8711-01	4	2
8	LLOYDMINSTER FIELD TANK SAND, 8708-03	3	1
9	COLD LAKE DESAND SLUDGE, 8704-04/05/06/07	2	2
10	SASKATCHEWAN CELTIC DESAND SLUDGE, 8708-01	1	2
11	LINDBERGH FIELD TANK SAND, 8710-01	4	1
12	LLOYDMINSTER DESAND SLUDGE, 8709-03/04	3	2
13	LINDBERGH DESAND SLUDGE, 8710-02	4	2
14	BROOKS PIT SLUDGE, 8713-02/03	5	3
15	LLOYDMINSTER ECOLOGY PIT MIXTURE, 8701-06	3	5
16	LLOYDMINSTER HEAVY OIL, 8702-01	3	4
17	LLOYDMINSTER SLUDGE, 8701-05	3	5
18	NOT AVAILABLE		
19	CELTIC DESAND SLUDGE BULK SAMPLE, 8708-05	1	2
20	KITSCOTY FIELD TANK SAND BULK SAMPLE, 8708-06	3	2

Table A.3.10 (Continued)

06613a

OILFIELD WASTES TREATMENT TEST PROGRAM
WASTE CONSTITUENT ANALYSIS DATA
(sorted by type)

SOURCE NUMBER (see legend)	1	8	11	10	3	9	4	12	2	13	7	14	5	16	15	6
UNATAC SAMPLE NUMBER	0709-01	0708-03	0710-01	0708-01	0712-01/20704-04/-05/6/7		0704-01/-02/03	0709-03/-04	0709-02 0711-01	0710-02	0711-01	0713-02/-03	0706-00	0702-01	0701-06	0708-02, 0709-1/2
CHEMEX LAB NUMBER	1016-10	1091-2	1016-7	1091-1	1016-6	1016-2	1016-5	1091-4	1016-9	1016-8	1016-3	1091-3	1016-4	1393-14	1393-4	1016-1
INDICATOR CHEMISTRY (values in ppm; negative values denote less than detection limits)																
aluminum	12.0	263	0.97	5.2	25.7	39.3	292	556	21.1	12.1	3.0	11.7	3.91	2.44	2140	0.24
barium	3.66	10.3	3.49	9.6	9.2	13.7	13.1	13.2	7.54	5.48	3.5	4.5	0.18	0.37	332	0.86
beryllium	-0.1	-0.1	-0.1	-0.1	-0.1	0.14	0.38	0.1	-0.1	-0.1	-0.1	-0.1	0.86	0.863	0.13	-0.1
boron	3.23	3.2	3.7	6.3	10.8	43.0	17.4	6.4	7.21	5.36	6.6	1.0	2.69	0.19	6.96	5.84
cadmium	0.21	-0.1	-0.1	0.1	2.54	1.32	5.26	-0.1	2.05	0.48	-0.1	-0.1	-0.1	-0.01	-0.01	-0.1
calcium	1176	320	426	3590	9500	9000	12000	2070	4060	1320	975	85.2	57.6	12.2	2190	4690
chromium	1.50	1.4	0.58	0.1	4.01	5.42	16.3	2.1	4.11	1.61	0.4	-0.1	-0.1	0.33	2.20	-0.1
cobalt	0.26	1.5	1.40	0.7	4.19	3.94	11.5	2.6	3.84	1.30	-0.1	0.2	-0.1	0.20	5.47	0.17
copper	0.64	1.7	0.60	0.3	0.89	4.74	10.3	9.8	2.45	1.00	0.1	0.4	0.86	0.22	5.61	0.80
iron	0.47	1200	0.80	-1	4.56	4.44	10.4	2500	2.01	1.24	-1	37.7	0.50	4.80	20.60	2.01
lead	0.0	17.1	6.1	-1	46.1	20.2	90.1	7.2	30.3	0.0	-1	2.2	-1	3.94	40.2	-1
lithium	11.3	1.4	6.83	0.0	24.2	9.93	21.7	3.0	16.6	9.16	2.0	0.6	-0.1	1.20	1.93	-0.1
magnesium	334	224	193	340	903	1210	155	660	700	700	767	23.8	6.0	12.4	755	300
manganese	0.44	26.0	0.83	1.6	3.00	0.76	1.07	35.5	11.7	13.5	2.9	1.6	-0.4	0.13	33.6	0.71
molybdenum	2.00	1.4	1.61	-0.1	30.5	16.7	43.4	2.5	9.9	5.02	3.1	0.5	2.00	0.70	4.90	1.52
nickel	2.36	5.7	2.30	-0.1	12.0	8.43	24.1	11.2	7.40	2.90	1.4	2.5	-0.1	26.6	19.5	1.63
potassium	87.6	83.7	167	120	175	402	440	135	192	191	163	50.3	7.70	0.93	303	140
silicon	60.7	3.9	63.1	70.4	96.2	006	59.1	7.6	75.4	00	03	3.2	7.45	1.54	310	105
sodium	1200	1200	1275	2560	1340	2360	975	1075	4150	2370	3700	150	01.0	30.0	1430	4420
strontium	15.3	15.0	12.1	00.4	30.9	42.0	44.9	01.3	50.7	36.0	36.4	2.5	0.43	0.14	71.3	54.1
titanium	-0.1	7.9	-0.1	-0.1	-0.1	2.93	3.79	0.9	1.11	0.32	0.1	1.0	0.20	0.32	22.0	-0.1
vanadium	10.7	5.5	3.17	6.9	13.1	9.45	16.2	12.9	23.7	14.1	37.0	19.2	46.9	53.0	19.2	0.90
zinc	0.14	12.5	0.37	2.2	2.49	0.95	4.54	350	2.50	2.40	4.0	11.9	0.00	1.01	27.4	-0.1
DETAILED CHEMISTRY																
antimony	0.22	0.00	0.16	0.12	0.00	3.0	7.5	0.13	0.11	0.11	0.11	0.15	0.14	0.010	0.20	0.39
arsenic	1.12	0.96	1.20	10.0	4.0	10.6	33.7	1.9	0.50	1.33	1.75	2.6	0.05	-0.001	0.05	10.0
chromium (hexavalent)	-0.03	-0.3	0.03	-0.3	0.190	0.15	0.970	-0.3	-0.03	0.00	-0.03	-0.3	-0.03	-0.003	0.060	-0.03
cyanide	-0.01	-0.01	-0.01	-0.01	-0.01	0.01	-0.01	-0.01	-0.01	-0.01	0.01	-0.01	-0.01	0.005	0.005	0.01
fluoride	-0.15	-1.0	-0.15	2.0	0.27	-0.15	-0.15	-1.0	-0.15	-0.15	-0.10	-1.0	-0.15	-5.0	-2.5	-0.15
lead (trace)	-0.2	not done	-0.2	-0.002	0.3	-0.2	0.2	not done	-0.2	-0.2	-0.002	-0.002	-0.2	not done	not done	0.2
mercury	0.030	0.014	0.043	0.019	0.500	0.403	1.100	0.049	0.030	0.051	0.009	0.015	0.031	-0.0006	0.0364	0.12
selenium	0.02	0.05	0.04	0.02	-0.02	0.02	-0.02	0.02	-0.02	-0.02	-0.02	0.03	0.03	-0.001	0.005	-0.02
IC SCAN (anions)																
chloride	10100	2050	3930	4040	430	9400	900	0710	4300	3450	7400	121	17.0	1.5	025	5510
nitrate	23.2	-1	45.0	-1	22.0	19.0	46.0	-1	23.0	22.0	-1	-1	10.6	0.6	0.5	42.5
nitrite	-1.0	-1	-1.0	-1	-1.0	-1	-1	-1	-1	-1.0	-1	-1	-1	-0.05	-0.5	-1
sulphate	-1	64	220	17	-1	-1	12.0	07	-1	-1	22	6	-1	5.0	42.5	19.7
bromide	3.2	64	0.9	17	0.5	10.1	1.6	07	9.9	9.4	11.9	6	0.5	0.05	3.4	30.6
iodide	1.7	7.6	0.3	15.6	-0.1	0.6	0.2	35	1.0	0.9	1.4	0.2	-0.1	-0.05	0.15	1.2
thiocyanate	-5	-0.1	-5	0.0	-5	-5	-5	1.2	-5	-5	-5	-0.1	-5	-0.5	-0.5	-5
thiosulphate	-1	-2	-1	-2	-1	-1	-1	-2	1.0	-1	-1	-2	-1	-0.5	1.0	2
carbonate	1700	-1	000	-1	5700	17700	21000	-1	300	400	_____	-1	600	not done	4000	2700
bicarbonate	not done	0.09	not done	0.3	not done	not done	not done	0.37	not done	not done	not done	_____	not done	not done	not done	not done

Table (continued)

os813a

OILFIELD WASTES TREATMENT TEST PROGRAM
WASTE CONSTITUENT ANALYSIS DATA
(sorted by type)

SOURCE NUMBER (see legend)	1	8	11	10	3	9	4	12	2	13	7	14	5	16	15	6
WHATAC SAMPLE NUMBER	8709-01	8708-03	8710-01	8708-01	8712-01/20704-04/-05/6/7		8704-01/-02/03	8709-03/-04	8709-02 8711-01	8710-02	8711-01	8713-02/-03	8704-08	8702-01	8701-06	8708-02, 8709-1/2
CHEMEX LAB NUMBER	1816-10	1891-2	1816-7	1891-1	1816-6	1816-2	1816-5	1891-4	1816-9	1816-8	1816-3	1891-3	1816-4	1393-14	1393-4	1816-1
GC/FID scan for BP of volatile organics (values are % in oil fraction, wet weight basis)																
BP RANGE (degrees C)	C0															
< 35	C 4-1	0.09	-0.05	0.32	0.18	0.21	0.20	0.12	2.10	0.10				0.01
36 - 60	C 4	0.05	0.00	0.34	0.12	0.29	0.10	0.06	0.06	0.05		0.13		0.71
61 - 97	C 7	0.34	1.33	0.06	0.35	0.02	0.50	0.61	0.77	0.16		0.39		0.77
98 - 125	C 8	1.52	2.35	1.02	0.95	2.05	1.43	1.41	1.63	0.53		0.79		1.05
126 - 150	C 9	1.21	1.01	1.65	0.94	1.40	1.10	1.15	2.25	0.79		1.05		1.04
151 - 173	C10	1.64	2.05	2.06	1.46	2.10	1.62	1.82	2.76	1.37	-0.01	1.50		1.87
174 - 195	C11	1.06	1.09	2.23	1.54	2.00	1.02	2.14	3.39	1.52	0.02	2.36		2.07
196 - 215	C12	2.23	1.95	3.41	2.39	2.79	2.13	2.75	3.00	2.55	0.10	3.02		2.51
216 - 235	C13	2.90	2.14	4.35	2.96	2.81	2.76	3.36	4.00	3.50	0.64	4.50		2.99
236 - 252	C14	3.40	2.40	4.02	3.49	3.79	3.37	4.03	4.10	4.62	1.59	5.00		3.40
253 - 270	C15	3.65	2.91	4.73	3.81	4.25	3.77	4.05	4.22	4.00	1.61	4.05		4.30
271 - 286	C16	2.50	2.92	4.21	4.15	4.20	3.61	5.10	3.95	4.29	2.21	4.20		4.46
287 - 301	C17	2.41	2.82	4.03	4.20	4.57	4.06	5.20	3.69	4.36	2.53	4.62		4.61
302 - 316	C18	4.12	3.43	4.24	4.02	4.47	4.06	4.01	3.59	4.07	3.23	4.02		4.39
317 - 330	C19	3.89	3.02	3.42	3.52	4.05	3.79	4.74	3.50	3.57	2.92	3.54		4.15
331 - 343	C20	4.42	3.22	3.32	3.29	4.45	4.30	5.35	2.99	3.71	3.09	3.51		4.57
344 - 356	C21	4.07	2.87	2.91	3.36	4.27	3.90	4.87	3.00	3.25	4.04	3.91		4.04
357 - 368	C22	3.53	3.01	2.55	3.31	3.83	3.51	3.90	2.65	3.20	4.37	4.01		3.65
369 - 379	C23	3.05	3.27	3.06	3.19	4.10	3.01	4.39	2.63	2.83	4.70	3.01		3.90
380 - 390	C24	4.27	4.20	2.61	2.76	3.97	3.94	4.65	2.69	2.83	4.63	3.41		3.70
391 - 401	C25	3.71	4.10	2.41	2.81	3.83	3.60	4.07	2.57	2.46	4.33	2.75		3.50
402 - 411	C26	2.85	4.21	2.06	2.96	2.35	3.29	3.00	2.66	2.75	4.56	2.75		3.29
412 - 421	C27	3.15	4.55	2.42	2.84	2.01	3.11	2.13	2.45	2.41	4.53	2.00		1.90
422 - 431	C28	2.84	3.99	2.71	2.70	2.13	3.01	2.13	2.23	2.53	4.00	3.00		1.87
432 - 440	C29	2.60	3.77	2.37	2.69	2.10	3.70	1.76	2.21	2.36	3.90	2.92		1.92
441 - 448	C30	2.55	3.59	2.12	2.40	1.87	3.29	1.92	1.90	2.24	3.76	2.72		1.56
449 - 458	C31	2.13	2.36	2.16	2.33	1.64	3.40	1.40	1.75	2.00	3.57	2.50		1.55
459 - 467	C32	2.23	2.26	1.84	2.06	1.75	3.05	1.56	1.80	2.02	3.53	2.62		1.53
468 - 475	C33	1.96	2.00	1.75	2.07	1.43	2.31	1.32	1.72	1.74	3.31	2.31		1.36
476 - 482	C34	2.10	1.89	2.03	2.22	1.73	1.60	1.56	1.72	1.84	3.05	1.97		1.60
483 - 490	C35	2.10	1.89	1.97	2.25	1.67	1.68	1.40	1.71	2.25	2.90	1.84		1.27
491 - 497	C36	2.22	1.65	1.96	2.44	1.69	1.66	1.74	1.54	2.13	2.85	1.71		1.62
498 - 504	C37	1.60	1.42	1.63	1.70	1.35	1.26	1.14	1.45	1.79	2.24	1.44		1.21
505 - 511	C38	1.47	1.32	1.50	1.70	1.34	1.10	1.17	1.60	1.75	2.11	1.44		1.29
512 - 518	C39	1.37	1.32	1.36	1.49	1.12	0.94	0.89	1.36	1.72	1.77	0.92		1.06
519 - 524	C40	1.20	1.23	1.25	1.23	1.09	0.89	0.85	1.44	1.71	1.60	0.92		0.88
525 - 530	C41	1.10	1.10	1.19	1.05	1.00	0.86	0.77	1.53	1.63	1.62	0.85		1.04
531 - 536	C42	1.00	1.10	1.12	1.23	0.88	0.94	0.74	1.29	1.59	1.39	0.80		1.12
537 - 542	C43	1.03	1.13	1.13	1.26	1.03	0.83	0.69	1.21	1.55	1.19	0.70		1.09
543 - 547	C44	0.90	1.13	1.10	1.32	1.02	0.77	0.64	1.46	1.55	1.27	0.65		1.10
548 - 553	C45	0.94	0.94	1.07	1.62	1.10	0.76	0.64	1.05	1.55	1.11	0.60		1.29
554 - 558	C46	0.93	0.90	1.01	1.46	1.14	0.70	0.62	1.32	1.54	4.59	2.21		1.60
559 - 564	C47	0.80	0.94	1.00	1.60	1.05	0.64	0.45	1.20	1.52				1.73
565 - 569	C48	0.84	0.80	0.99	1.39	0.97	0.55	0.45	1.19	1.43				1.37
570 - 575	C49	0.83	0.80	0.75	1.33	1.10	0.55	0.34	1.06	1.30				1.78
>575	C50+	0.70	0.71	0.95	1.24	0.90	0.32	0.34		1.27				1.64

A.3.10

Table (concluded)

PSE13a

OILFIELD WASTES TREATMENT TEST PROGRAM
WASTE CONSTITUENT ANALYSIS DATA
(sorted by type)

SOURCE NUMBER (see legend)	1	1	8	11	10	3	9	4	12	2	13	7	14	5	16	15	6
URATAC SAMPLE NUMBER	0709-01	0708-03	0710-01	0708-01	0712-01/20704-04/ -05/6/7		0704-01/ -02/03	0709-03/ -04	0709-02 0711-01	0710-02	0711-01	0713-02/ -03	0704-08	0702-01	0701-06	0708-02, 0709-1/2	
CHEMEX LAB NUMBER	1016-10	1091-2	1016-7	1091-1	1016-6	1016-2	1016-5	1091-4	1016-9	1016-8	1016-3	1091-3	1016-4	1393-14	1393-4	1016-1	
ANALYSES OF FREE WATER																	
chromium (hexavalent) in water						0.400			0.150								
cyanide in water fraction						0.075			0.070		0.074						
chloride in water fraction						33000			37400		42200						
nitrate in water fraction						-50			21.0		-1						
nitrite in water fraction						-50			-1		-1						
sulphate in water fraction						-1			151		4.6						
bromide in water fraction						42					125						
iodide in water fraction						1.7					9.5						
thiocyanate in water fraction						-5					-5						
thiosulphate in water fraction						1					-1						

Source: Environment Canada & Alberta Oil Sands Technology and Research Authority

Appendix B
ENVIRONMENTAL REGULATIONS/AMENDMENTS

Table B.1 Amendment to Class 9 Definition of the TDGA Regulations

Parameter	Concentration in Waste Extract (mg/L)
Aldrin + Dieldrin	0.07
Arsenic	5.0
Barium	100.0
Boron	500.00
Cadmium	0.5
Carbaryl/1-Naphthyl-N-methyl carbamate/Sevin	7.0
Chlordane	0.7
Chromium	5.0
Cyanide	20.0
2,4-D	10.0
DDT	3.0
Diazinon/Phosphordithioic acid O,O-diethyl O-(2-isopropyl 6-methyl-4-pyromidinyl)ester	0.02
Endrin	0.02
Fluoride	150.0
Heptachlor + Heptachlor epoxide	0.3
Lead	5.0
Lindane	0.4
Mercury	0.1
Methoxychlor/1,1,1-Trichloro-2, 2-bis (p-methoxyphenyl) ethane	10.0
Methyl Parathion	0.7
Nitrate + Nitrite	1000.0
Nitrilotriacetic acid	5.0
Nitrite	100.0
Parathion	3.5
Polychlorinated Biphenyls	0.3
Selenium	1.0
Silver	5.0
Toxaphene	0.5
2,4,5-TP/Silvex/2-(2,4,5-Trichlorophenoxy) pripionic acid	1.0
Trihalomethanes	3.50
Uranium	2.0

Appendix C
DETAILED EVALUATION OF PROCESSES

TABLE C.1a ASSESSMENT OF SHORTLISTED TREATMENT PROCESSES - PROCESS EVALUATION WORKSHEET

SMALL PLANT DETAILED EVALUATION CRITERIA												
PROCESS		OPER-ABILITY	PERFORM-ANCE	PORT-ABILITY	POTENTIAL FOR COMMER-CIALIZATION	FLEXIBILITY OF PROCESS TO HANDLE VARYING FEEDS	FIELD EXPERIENCE IN SIMILAR APPLICATION	EXPAND-ABILITY	TECHNOLOGY BUILDS ON OR ENHANCES CURRENT PRACTICE	OPERATIONAL SAFETY RISK	RELATIVE COST	TOTAL
WEIGHTING		140	130	100	50	120	100	50	90	110	110	
CF Systems	Rating	4	8	7	10	6	10	9	7	2	5	
	Score	560	1040	700	500	720	1000	450	630	220	550	6370
B.E.S.T.	Rating	5	8	7	10	6	10	9	4	4	5	
	Score	700	1040	700	500	720	1000	450	360	440	550	6460
Hot Toluene Fluid Extraction	Rating	5	8	7	3	6	5	9	4	4	5	
	Score	700	1040	700	150	720	500	450	360	440	550	5610
BP Oil Sovent Extraction	Rating	5	8	7	10	6	10	9	7	2	5	
	Score	700	1040	700	500	720	1000	450	630	220	550	6510
USEPA Soil Washer	Rating	7	6	9	9	3	6	9	6	5	7	
	Score	980	780	900	450	360	600	450	540	550	770	6380
RTR/Gulf	Rating	6	4	8	3	4	5	8	6	5	7	
	Score	840	520	800	150	480	500	400	540	550	770	5550
TSCUK Processor	Rating	4	9	2	9	7	10	6	2	3	3	
	Score	560	1170	200	450	840	1000	300	180	330	330	5360
Rotary Kiln	Rating	3	10	2	10	7	5	5	1	1	3	
	Score	420	1300	200	500	840	500	250	90	110	330	4540
Soil Slurry Biodegradation	Rating	3	4	2	5	3	4	5	1	6	5	
	Score	420	520	200	250	360	400	250	90	660	550	3700
Land Farming	Rating	4	4	1	9	3	6	4	8	6	5	
	Score	560	520	100	450	360	600	200	720	660	550	4720
Solidification/ Fixation	Rating	3	1	1	6	1	3	6	3	6	3	
	Score	420	130	100	300	120	300	300	270	660	330	2830
In Situ Biolog. Treatment	Rating	3	4	1	5	3	2	6	3	6	5	
	Score	420	520	100	250	360	200	300	270	660	550	3830
Industrial Landfill	Rating	6	1	1	9	10	1	5	8	6	5	
	Score	840	130	100	450	1200	100	250	720	660	550	5000
Agliofloat	Rating	2	5	7	6	5	5	7	2	5	5	
	Score	280	650	700	300	600	500	350	180	550	550	4660
Coil Treater	Rating	6	1	2	10	1	2	6	6	5	5	
	Score	840	130	200	500	120	200	300	720	550	550	4110
Oleophilic Sieve	Rating	7	1	8	8	2	3	8	4	5	5	
	Score	980	130	800	400	240	300	400	360	550	550	4710
COMMENTS					10=Commercial unit available	All have limitations		Assume scale of expansion is 2X,not 10X				

TABLE C.1b ASSESSMENT OF SHORTLISTED TREATMENT PROCESSES - PROCESS EVALUATION WORKSHEET

LARGE PLANT DETAILED EVALUATION CRITERIA

PROCESS		OPER-ABILITY	PERFORM-ANCE	PORT-ABILITY	POTENTIAL FOR COMMER-CIALIZATION	FLEXIBILITY OF PROCESS TO HANDLE VARYING FEEDS	FIELD EXPERIENCE IN SIMILAR APPLICATION	EXPAND-ABILITY	TECHNOLOGY BUILDS ON OR ENHANCES CURRENT PRACTICE	OPERATIONAL SAFETY RISK	RELATIVE COST	TOTAL
WEIGHTING		100	140	50	120	130	100	90	50	80	140	
CF Systems	Rating	4	8	7	10	6	10	9	7	2	5	
	Score	400	1120	350	1200	780	1000	810	350	160	700	6870
B.E.S.T.	Rating	5	8	7	10	6	10	9	4	4	5	
	Score	500	1120	350	1200	780	1000	810	200	320	700	6980
Hot Toluene Fluid Extraction	Rating	5	8	7	3	6	5	9	4	4	5	
	Score	500	1120	350	360	780	500	810	200	320	700	5640
BP Oil Sovent Extraction	Rating	5	8	7	10	6	10	9	7	2	5	
	Score	500	1120	350	1200	780	1000	810	350	160	700	6970
USEPA Soil Washer	Rating	7	6	9	9	3	6	9	6	5	7	
	Score	700	840	450	1080	390	600	810	300	400	980	6550
RTR/Gulf	Rating	6	4	8	3	4	5	8	6	5	7	
	Score	600	560	400	360	520	500	720	300	400	980	5340
Taciuk Processor	Rating	4	9	2	9	7	10	6	2	3	3	
	Score	400	1260	100	1080	910	1000	540	100	240	420	6050
Rotary Kiln	Rating	3	10	2	10	7	5	5	1	1	3	
	Score	300	1400	100	1200	910	500	450	50	80	420	5410
Soil Slurry Biodegradation	Rating	3	4	2	5	3	4	5	1	6	5	
	Score	300	560	100	600	390	400	450	50	480	700	4030
Land Farming	Rating	4	4	1	9	3	6	4	8	6	5	
	Score	400	560	50	1080	390	600	360	400	480	700	5020
Solidification/ Fixation	Rating	3	1	1	6	1	3	6	3	6	3	
	Score	300	140	50	720	130	300	540	150	480	420	3230
In Situ Biolog. Treatment	Rating	3	4	1	5	3	2	6	3	6	5	
	Score	300	560	50	600	390	200	540	150	480	700	3970
Industrial Landfill	Rating	6	1	1	9	10	1	5	8	6	5	
	Score	600	140	50	1080	1300	100	450	400	480	700	5300
Agliofloat	Rating	2	5	7	6	5	5	7	2	5	5	
	Score	200	700	350	720	650	500	630	100	400	700	4950
Coil Treater	Rating	6	1	2	10	1	2	6	8	5	5	
	Score	600	140	100	1200	130	200	540	400	400	700	4410
Oleophilic Sieve	Rating	7	1	8	8	2	3	8	4	5	5	
	Score	700	140	400	960	260	300	720	200	400	700	4780
COMMENTS					10=Commercial unit available	All have limitations		Assume scale of expansion is 2X,not 10X				

C. DETAILED EVALUATION OF PROCESSES

The following discussion summarizes and describes in general terms the rationale for the rating/assessment of processes presented in Tables C.1a and C.1b.

The rating/assessment of technologies/processes was carried out by CH2M HILL using a team approach and involved both project and senior technical advisory staff. The following staff provided input to the assessment:

- Barry Asano - Project Manager
- Henry Yau - Process Engineer
- Jeff Chan - Process Engineer
- Deborah Ross - Process Engineer
- Jay Mackie - Senior Technical Advisor
- Calvin Brunner - Senior Technical Advisor
- Bill Byers - Senior Technical Advisor

C.1 OPERABILITY

The operability criterion relates to the reliability, simplicity, and stability of a process or system. No one process was found to be outstanding as defined by this criterion. Of the processes listed, the Oleophilic Sieve and U.S. EPA Soil Washer rated the highest in terms of being relatively simple systems with high service factors, minimal pretreatment requirements, and low operating and maintenance requirements. These were followed closely in the rating by the Colt Treater, industrial landfill, and RTR/Gulf. Solvent-extraction-based processes such as CF Systems, B.E.S.T., Hot Toluene Fluid Extraction, and BP Oil Solvent Extraction were downrated in this category because of their complexity and higher maintenance requirements. Taciuk Processor and landfarming were also deemed to be processes requiring high maintenance. The lowest-rated processes scoring only 2 or 3 points are quite complex processes, requiring high maintenance, offering low service factors, and requiring more pretreatment in this application.

For the small plant evaluation the rating for the individual processes is the same as in the large plant evaluation. The importance of operability, however, becomes more pronounced for the small plant evaluation and this is reflected in its increased weighting for the small plant scenario.

C.2 PERFORMANCE

A system's performance is its ability to treat the waste with high recovery, destruction, or removal efficiencies and good turndown capability while yielding a product that meets or exceeds the outlet quality requirements by a reasonable margin of safety and a residue that is low in volume and readily disposed of in an acceptable manner.

Thermal treatment processes such as rotary kiln and the Taciuk Processor score the highest relative to the others. In many cases, thermal treatment is the most efficient method for destruction of organics. It also significantly reduces the volume of inorganics such as metal and salt, and reduces their mobility so that the residue can be effectively disposed of. Physical and chemical processes such as CF Systems, B.E.S.T., Hot Toluene Fluid Extraction, and BP Oil Solvent Extraction are also expected to have relatively high recovery/removal efficiencies as demonstrated by limited published results. However, to date these technologies have not been as well established as thermal treatment methods. Other processes evaluated such as Aglofloat, in situ biological treatment, soil slurry biodegradation, and the RTR/Gulf Process are still in their development/piloting stage and their performances are not sufficiently defined. Solidification/fixation and industrial landfill scored low because they neither destroy nor remove contaminants. The Colt Treater is only applicable to a very narrow range of wastes considered in this study. The performance of the Oleophilic Sieve was reported to be poor for the type of wastes considered in this study.

The performance criterion is only slightly less important for the small plant scenario than it is in the large plant scenario.

C.3 PORTABILITY

A mobile unit is considered the most portable. Skid-mounted units are more transportable than fixed plants. The U.S. EPA Soil Washer is a fully mobile unit mounted on a trailer and thus scored the highest in this category. The RTR/Gulf, Aglofloat, Oleophilic Sieve, CF Systems, B.E.S.T., Hot Toluene Fluid Extraction, and BP Oil Solvent Extraction have either mobile units available or are reported to be compact in size and readily transportable in modules. The Taciuk Processor, rotary kiln, and soil slurry biodegradation technologies generally require many interconnected process units or large vessels and therefore are difficult to move. Landfarming, solidification/ fixation, in situ biological treatment, and industrial landfill are site specific treatment processes.

The portability criterion is much more important in a small plant scenario than in a large plant. In the small plant scenario, it is reasonable to assume that, because of economics, the treatment unit would be brought to the waste sites on a rotational basis. In contrast, wastes generated within a regional boundary would be brought to a central treatment facility in the large plant scenario. This philosophy is reflected in the portability weighting for small plants being twice the weighting for large plants.

C.4 POTENTIAL FOR COMMERCIALIZATION

Under this criterion, those technologies with the least anticipated scale-up problems and the least need for additional pilot testing have the highest potential for commercialization. A number of technologies investigated here have demonstrated full-scale application. These include CF Systems, B.E.S.T., BP Oil Solvent Extraction, rotary kiln, and the Colt Treater. Others that have been fully demonstrated in pilot scale and are readily approaching commercialization are the U.S. EPA Soil Washer, the Taciuk Processor, and the Oleophilic Sieve. Some technologies score relatively low in this category because they are in very early stages of development.

These include the Hot Toluene Fluid Extraction, RTR/Gulf, soil slurry biodegradation, solidification/fixation, in situ biological treatment, and Aglofloat. It should be noted that the opinions stated above are based on information received at the time of writing. Some of the developing technologies may be rapidly advancing to commercial stage.

The importance of this criterion is related to the size of the operation. For small investments (i.e., small plants) the stake is small and therefore a higher risk of investment loss is generally acceptable. For large plants with substantial investment, this risk is generally minimized by adapting well-proven and demonstrated, commercially available technologies.

C.5 FLEXIBILITY OF PROCESS TO HANDLE VARYING FEEDS

Under this criterion, those technologies that have demonstrated the flexibility to handle a wide range of feed characteristics (i.e., particle size, oil/water/solid composition) scored higher. This criterion is probably the most difficult one to meet for all the technologies investigated since they all have limitations regarding feed specifications. In general, however, solvent extraction and thermal processes have demonstrated the capability to treat a wider range of waste feed than processes such as aqueous leaching, biological treatment, and physical separation. For example, aqueous leaching is generally not economical when the feed consists of significant amounts of fines that are less than 50 microns in diameter. Toxic constituents such as some heavy metals are detrimental to biological treatment. The amounts of free water and hydrocarbon in the feed have major implications on processes such as thermal treatment and solidification and fixation.

The flexibility of a process to handle the varying feed criterion is weighted slightly higher for the large plant scenario. The rationale is that a large central plant would be required to handle a wide range of feed material brought in from various fields while small plants could be designed to handle specific types of wastes.

C.6 FIELD EXPERIENCE IN SIMILAR APPLICATIONS

Under this criterion, those technologies that have demonstrated actual field experience with similar waste types and environmental conditions scored higher. Technologies investigated that met this criterion include CF Systems, B.E.S.T., BP Oil Solvent Extraction, and the Taciuk Processor. Technologies having limited field experience or having demonstrated field experience but under different environmental conditions are Hot Toluene Fluid Extraction, U.S. EPA Soil Washer, RTR/Gulf, rotary kiln, soil slurry biodegradation, landfarming, and Aglofloat. Technologies still in their developmental stage with very limited field experience are solidification/fixation, in situ biological treatment, industrial landfill, Colt Treater, and the Oleophilic Sieve.

It is felt that field experience in similar applications is as important for the large plant scenario as for the small plant and equal weightings have been assigned to both categories.

C.7 EXPANDABILITY

Under this criterion, modular type construction using existing, well-proven pieces of equipment are expected to be the least expensive to expand. The majority of the technologies investigated scored fairly high in this category. Most of the technologies make use of vessels, tanks, pumps, screens, centrifuges, heat exchangers, dryers, decanters, and other material-handling equipment that are well proven in the chemical processing industry. Exceptions are landfarming and industrial landfill, because of the potential difficulty in acquiring suitable land, and soil slurry biodegradation due to the large tankage involved.

A higher weighting is assigned to the large plant scenario because of the potential cost saving due to economy of scale. It would also be more economical to build a large central plant than to expand smaller local plants.

C.8 TECHNOLOGY BUILDS ON OR ENHANCES CURRENT PRACTICE

Under this criterion, those technologies that are similar to current oilfield practices scored higher because they are easier to adopt by existing operating and maintenance staff. Current practices include gravity separation with or without heat input, use of waste material for road construction, deep well disposal, and landfarming or landspreading. It is apparent that the technologies summarized in this document are generally much more complex than most current practices. In order to conduct a meaningful assessment, the scope of current practices was expanded to include typical operation of a production battery such as free water knockout, treaters, dehydration, and desanding. These operations are basically physical/chemical processes applied to the product stream.

Treatment technologies that scored relatively high under this criterion are physical/chemical processes such as CF Systems, BP Oil Solvent Extraction, U.S. EPA Soil Washer, RTR/Gulf, and the Colt Treater. Landfarming and industrial landfill also scored high. Processes such as the rotary kiln, soil slurry biodegradation, Aglofloat, and the Taciuk Processor scored relatively low because of their unique nature.

The weighting for this criterion was assigned a higher value for the small plant scenario than for the large plant. The rationale follows that in a small plant environment, technical resources are limited to operate and maintain a high-tech system.

C.9 OPERATIONAL SAFETY RISK

Under this criterion, technologies operating in low temperature, low pressure environments using nontoxic substances have a lower safety risk to operators and thus scored higher than technologies operating in high temperature, high pressure environments using toxic substances.

Technologies that scored relatively higher under this criterion are biological, low temperature/physical, and solidification/fixation technologies. The U.S. EPA Soil Washer and RTR/Gulf Process

also scored quite high because of their low pressure and temperature operating environment. Solvent extraction and thermal treatment processes scored the lowest due to their high pressure and/or temperature requirements.

A higher weighting is assigned to the small plant scenario. The rationale follows that current technology exists to allow appropriate safety features to be incorporated into plant design. The impact is higher cost. A large central plant is better able to absorb this cost than a smaller plant.

C.10 RELATIVE COST

Treatment technologies with lower relative cost scored higher under this criterion. In general, physical treatment processes cost less than physical/chemical or biological processes; physical/chemical or biological processes cost less than thermal treatment processes.

For the technologies investigated, the U.S. EPA Soil Washer and the BP Oil Solvent Extraction process are expected to have a lower relative cost. In comparison, the Taciuk Processor, the rotary kiln, and solidification/fixation are expected to have a higher relative cost.

A higher weighting is assigned to the large plant scenario. The rationale follows that cost effectiveness is often the deciding factor for the construction of a large, full-scale commercial facility, whereas in some cases, other reasons, such as research and development, may be the driving force behind the implementation of a small-scale pilot project.

Appendix D
PROCESS TECHNOLOGY DESCRIPTIONS

D PROCESS TECHNOLOGY DESCRIPTIONS

D.1 SOLVENT EXTRACTION TREATMENT

CF Systems Extraction (CF)

Process Description

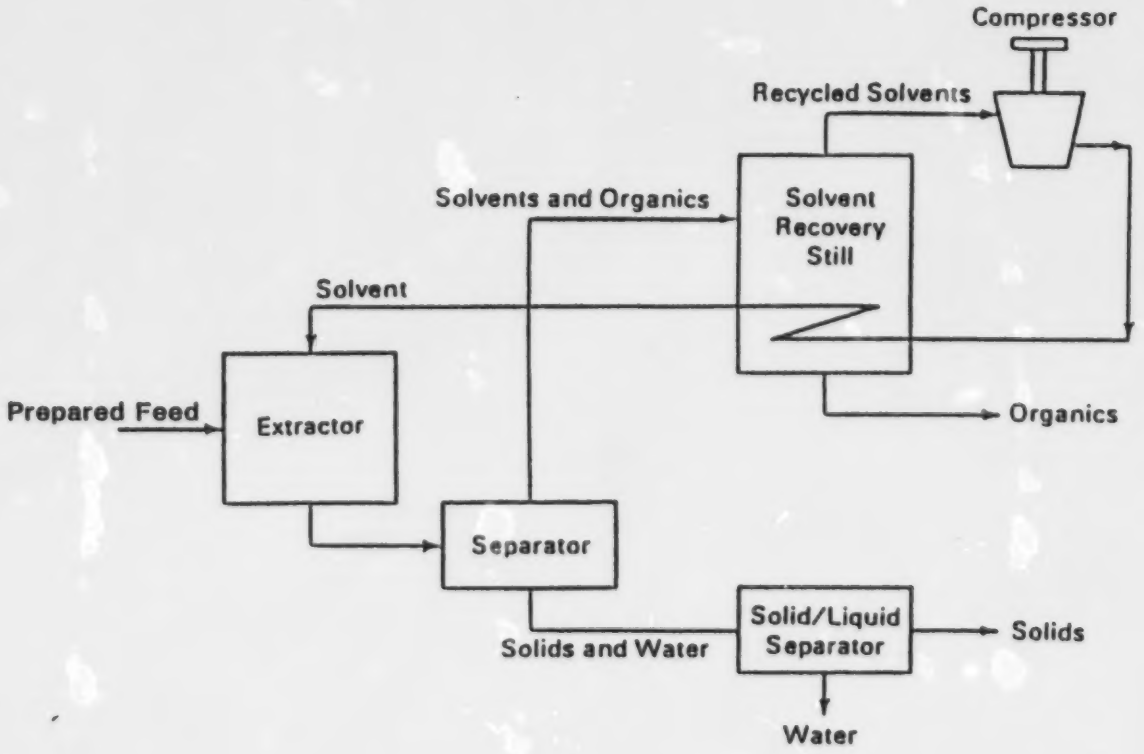
Critical fluids (CF) are condensed gases or supercritical fluids such as carbon dioxide, freon, propane, ethylene, ammonia, and others in the vicinity of their critical points. In their liquid state, these fluids are capable of dissolving organic compounds. Phase separation is then accomplished by manipulating the extraction temperature and pressure. CF Systems Corporation of Waltham, MA, developed a critical fluid extraction process using propane for sludge treatment.

In a typical process, solids or sludges are slurried through a shaker screen to remove solids larger than 3 mm in diameter. Large solids captured by the screen are collected, washed, and disposed of.

Sludge passed through the screen is collected in a storage tank. Chemicals may be added to maintain a pH between 6 and 8. The slurry is then pumped to a concentrator. The concentrator thickens the slurry to about 50 percent solids. Water extracted by the concentrator is disposed of. The thickened solids slurry is pumped to a holding tank from which the extraction unit is fed.

The extraction unit operates on a continuous basis in a countercurrent manner. The prepared feed is processed in a series of extractor/separators. Water and cleaned solids are dewatered using a belt filter press, producing a sludge cake with 40 to 45 percent solids content. Effluent water is disposed of and dewatered solids are landfilled. Recovered oil is returned to crude treaters and the recovered solvent is recycled back to the extraction unit.

Figure D-1 presents a simplified schematic for the CF solvent extraction process.



Source: CF Systems, Corporation

Figure D.1

CF SYSTEMS EXTRACTION SCHEMATIC

Application

Examples of organic pollutants that can be extracted using the CF solvent extraction process include chlorinated hydrocarbons, phenols, benzene and benzene derivatives, alcohols, ketones, acids, oil, and greases. It is applicable to liquid wastes, sludges, and solids with appropriate feed preparation. This system is commercially available.

Basic Extraction Sludge Treatment (B.E.S.T.) Process

Process Description

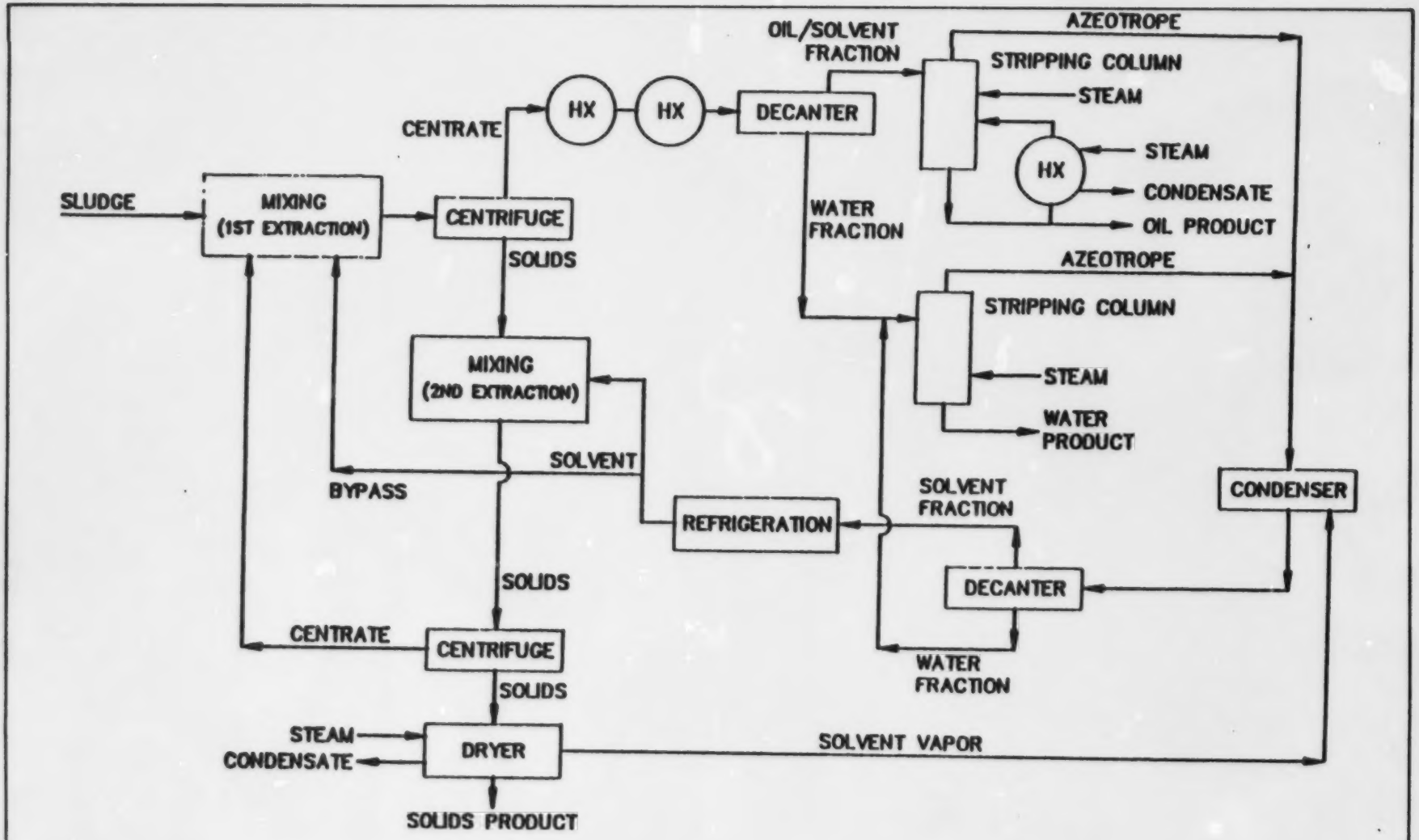
The B.E.S.T process developed by Resource Conservation Company (RCC) of Bellevue, Washington, is a solvent extraction technology that uses the unique properties of aliphatic amines to break down suspensions and emulsions in sludges and contaminated soils. At around 4°C, triethylamine dissolves both oil and water. At around 18°C, it dissolves only oil. This change in solvent characteristics forms the basis for the B.E.S.T. process.

Figure D-2 schematically illustrates the two primary stages of the B.E.S.T. process, the cold stage and the hot stage. In the cold stage sludges or soils are mixed with amine at low temperatures (<20°C). The mixture ratio is a function of feed composition, but is often on the order of two parts amine for each part of sludge. At this temperature, liquid fractions are soluble and suspensions and emulsions are virtually eliminated. The solids fraction becomes readily separable and can be removed by filter or centrifuge and dried. Since the amine is alkaline (pH~10), heavy metals in the sludge are converted to hydrated oxides that precipitate and exit the process with the solids fraction.

In the hot stage, the single phase amine/water/oil fraction is heated to a temperature above the miscibility temperature (>20°C). Two distinct phases form after heating: amine/oil and water. These phases are then separated by decanting. The final steps in this process involve solvent recovery, which is generally accomplished by thermal means.

Figure D-3 is a process flow diagram for the B.E.S.T. process that illustrates one way to assemble individual process elements to accomplish the separation described above. This configuration was employed by RCC in a 100-ton/day system (nominal wet feed capacity). In this configuration the process is employed primarily for pumpable materials such as sludges. Modification to the front end of the process can facilitate the treatment of soils.

Sludge is introduced to a mix tank and combined with refrigerated solvent. The solvent has been chilled sufficiently that

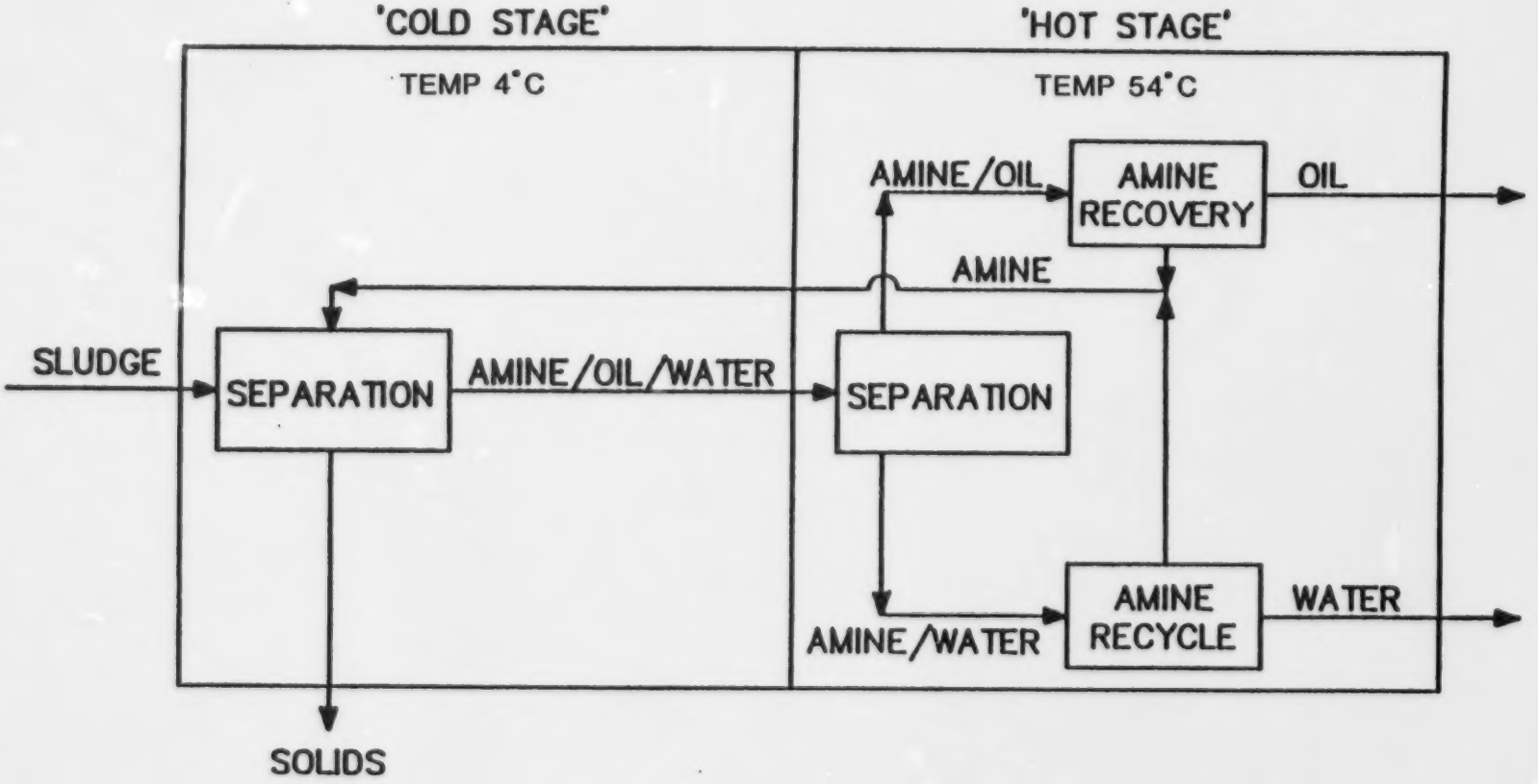


Source: Resources Conservation Company

Figure D.3

B.E.S.T. BLOCK FLOW DIAGRAM

CH2MHILL



Source: Resources Conservation Company

Figure D.2

B.E.S.T. SCHEMATIC

CH2MHILL

the resulting temperature is below the miscibility temperature (<20°C). Sufficient residence time is provided to permit complete solvation and formation of a single liquid phase. Solids are separated from the liquid by centrifugation. The use of centrifugation speeds up solids separation and helps ensure a high capture rate for submicron size particles, which are often the cause of emulsion formations.

A second solids washing step is employed for high oil sludges (>10 percent oil) if it is necessary to ensure the product solids contain less than 1 percent (wt) residual oil and grease. Additional washing steps may be employed if even lower oil concentration in the solids is necessary. The solids cake from the final extraction step goes to a closed, indirectly heated dryer. Vaporized solvent is drawn off the dryer, condensed, and reused in the process. Dried solids typically contain greaten than 99 percent solid matter.

Liquid from the first mixing step is heated and introduced to a decanter vessel. Sufficient residence time is provided in the decanter to ensure complete separation into amine/oil and water phases. The amine/oil phase is drawn off the top of the decanter and pumped to an amine recovery system. This system may consist of an amine evaporator or an evaporator combined with a finishing distillation column. Recovered solvent is condensed and reused. The oil in the column bottoms is reused.

The water phase is drawn off the bottom of the decanter and pumped to a stripping column for solvent recovery.

Applications

The B.E.S.T. process has been used successfully for treatment cleanup of a Superfund site in Georgia. The site has four unlined lagoons containing acidic (pH <2) oily sludges, piles of oily filter medium, and oil/water separator pits. All sludges contained low levels of PCBs (<10 mg/L) and a prevalency of heavy metals.

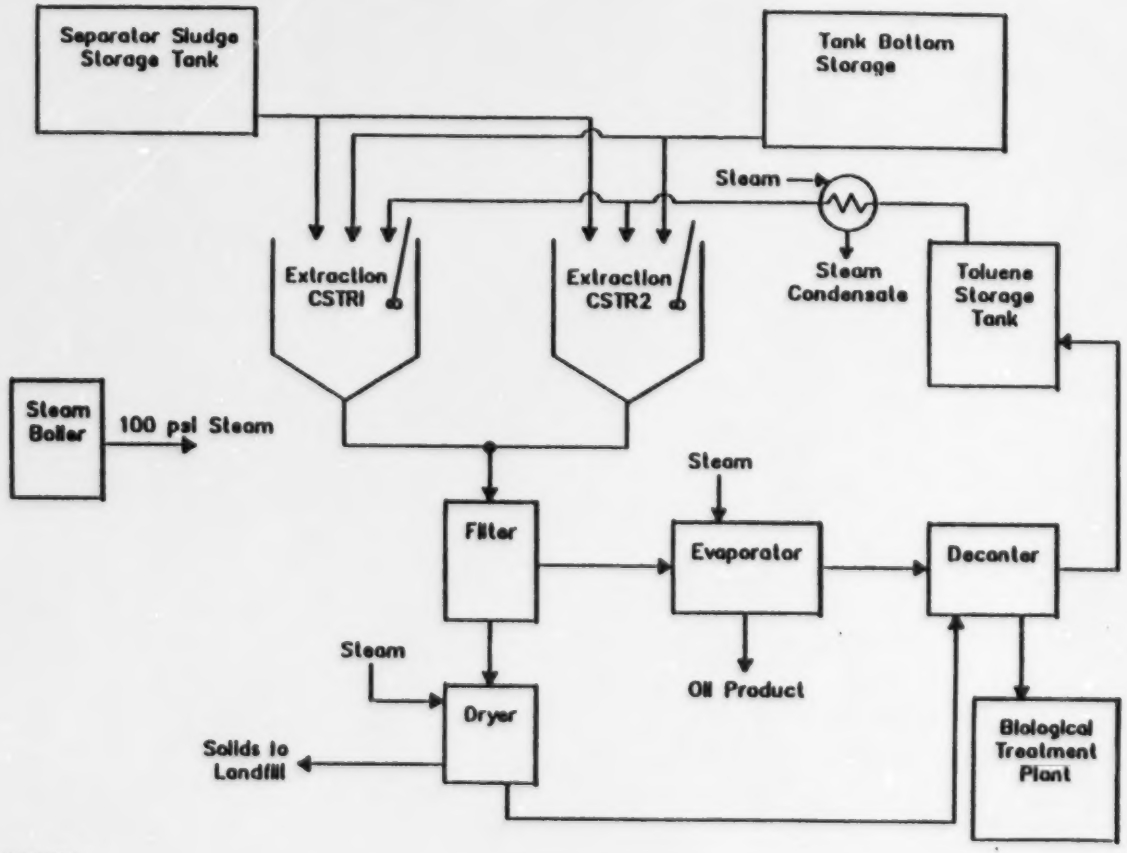
Hot Toluene Solvent Extraction

Process Description

The hot toluene solvent extraction process was developed by Tricil Limited for the treatment of mainly separator and tank bottom sludges. A conceptual design schematic is presented in Figure D-4. The sludge is stored in feed tanks and fed to a mixing tank where heated toluene is added. The mixture is filtered to separate the solids and liquid phases. The liquid stream from the filter is sent to an evaporator where the oil product is recovered. Solvent is separated in a decanter and recycled back to the process. The water is discharged to a biological treatment plant. The damp solids are dried at a temperature that is above the solvent boiling point (111°C). The dried solids are discharged for landfilling. The solvent is recovered in the decanter.

Application

Tricil piloted the process using several barrels of tank bottom and separator sludges from refineries located in Ontario and Quebec.



Source: Tricil Limited

Figure D.4

HOT TOLUENE EXTRACTION PROCESS CONCEPTUAL DESIGN

CH2M HILL

BP Oil Solvent Extraction

Process Description

The BP oil solvent extraction process is a union of three distinct technologies (Figure D-5) which together yield a chemically-fixed residue. These are mechanical treatment for volume reduction by the recovery of water and hydrocarbons; solvent extraction for residual hydrocarbon recovery; and chemical fixation for constituent immobilization.

The first unit in the process is mechanical treatment. The objective is to a remove considerable amount of water and most of the oil from the feed. Sludge material is pumped to intermediate tankage where filtration aids are added and the mixture is homogenized. The conditioned sludge mixture is then charged to a recessed plate filter press. During the operating cycle, solids are filtered out and accumulate in the filter press chambers, while the oil and water are removed from the system and separated. The recovered oil is returned to the crude unit for reprocessing while the filtrate water is disposed of.

The central unit operation of the process is a batch extraction vessel. It is designed to remove hydrocarbon compounds present in the dewatered oily sludge material. The extraction of oil is accomplished by contacting the sludge with hydrocarbon solvents. The deoiled solids are then slurried with water and pumped out of the extractor as a deoiled sludge water slurry.

The third unit operation of the process is fixation (stabilization). This is conducted in a conventional filter press which receives the deoiled sludge water slurry. The dewatering step is accompanied by pozzolanic reactions which immobilize metals and other constituents in the product residue. Fixation reduces the leachability of the metals and other contaminants.

Application

The process has been developed to process refinery oily solid wastes, slop oil emulsion solids, heat exchanger bundle solids, tank and pit bottom sludges.

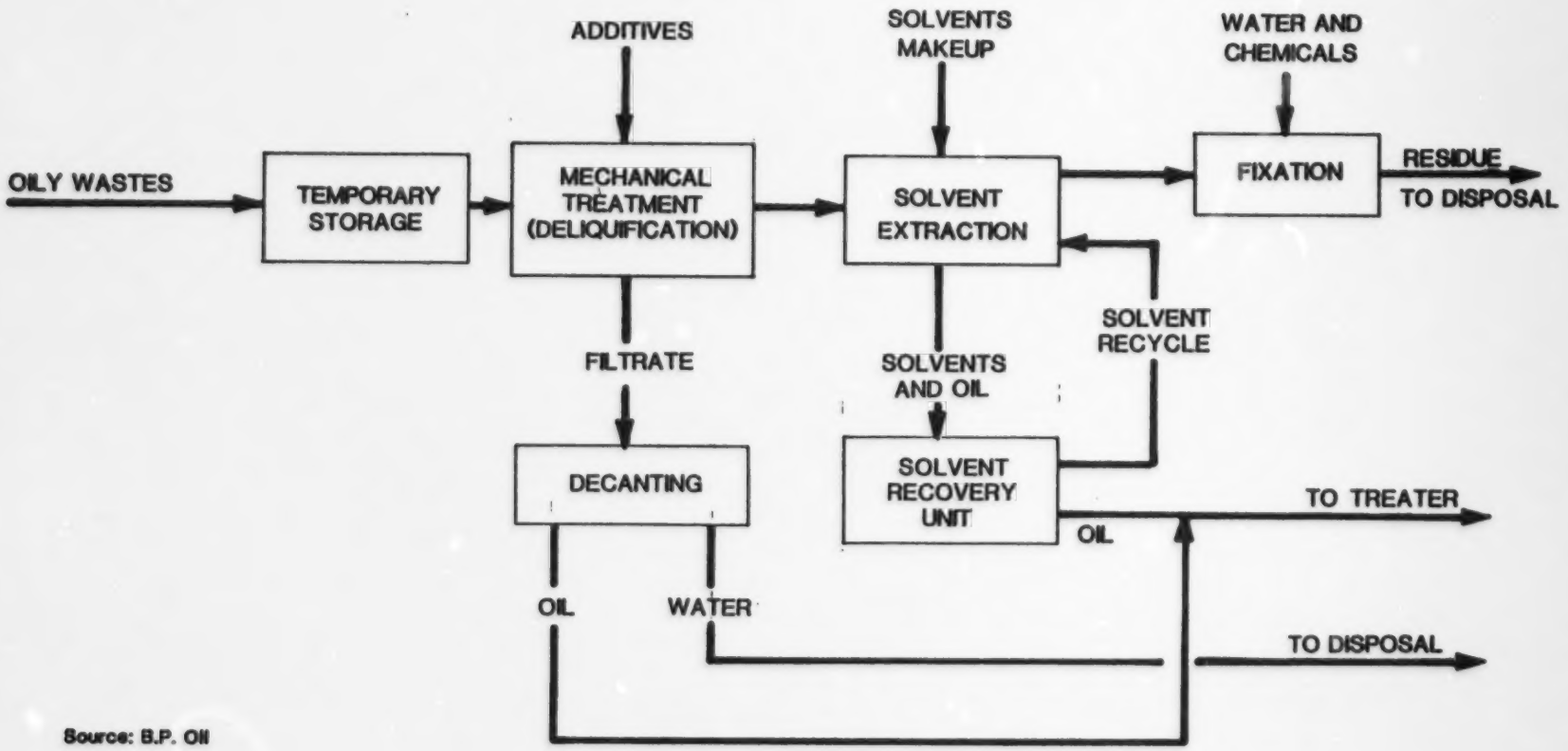


Figure D.5

BP OIL SOLVENT EXTRACTION BLOCK FLOW DIAGRAM

CH2MHILL

Status of Development

A 15-t/d demonstration plant was constructed and operated at BP's Alliance Refinery in Belle Chasse, CA. A full-scale demonstration plant is currently operating in Prudhoe Bay, Alaska.

D.2 AQUEOUS EXTRACTION/LEACHING

USEPA Mobile Soil Washer

Process Description

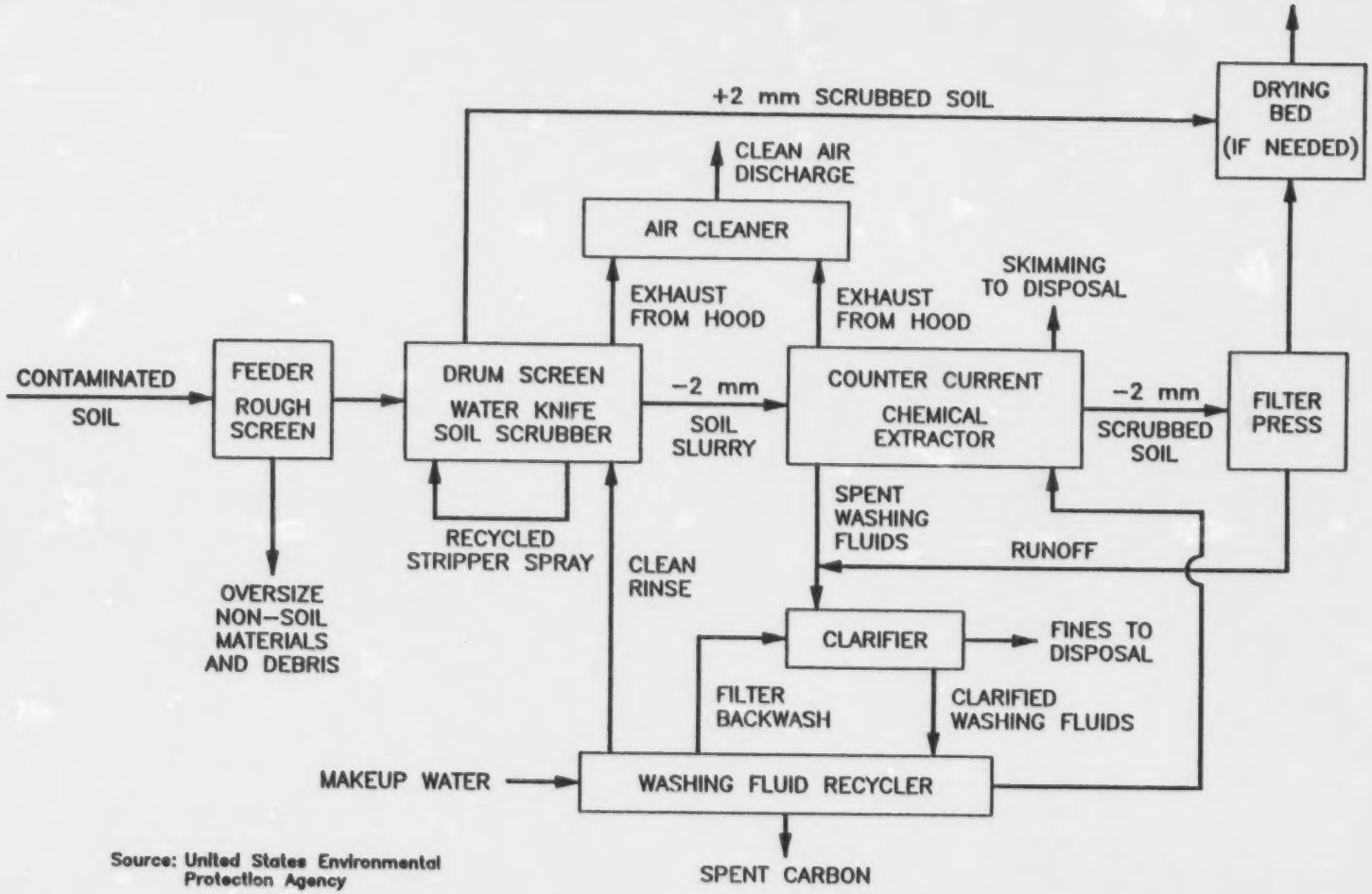
The mobile treatment system is designed for water extraction of a broad range of hazardous materials from spill-contaminated soils. The system consists of three basic components: a drum washer, a countercurrent extraction unit, and a dewatering unit. Figure D-6 presents a process flow schematic diagram for the soil washer.

Contaminated solids are fed into a hopper. Large pieces greater than 2.5 cm are rejected. The solids then pass into a tilted drum washer. Operational rates are 22.7 m^3/h at 690 kPa through a series of high pressure water knives to break up solids into greater than and less than 2-mm fractions (coarse-grained sand break). A soaking zone allows for greater than 2-mm solids to be contacted and tumbled in the wash solution for about 10 minutes. A rinse and dewatering screen removes any residual fine soil particles and wash solution. Material then exits the washer as clean, coarse material. Fine material (less than 2 mm) is pumped to the countercurrent extraction unit.

The extraction unit is comprised of four contactors which sequentially mix contaminated fine soil material with the wash solution. Each contactor has an aerator/agitator and a hydrocyclone mounted on it. Influent solids are fed into the first contactor and water is fed into the fourth contactor. Chemicals can be added to any of the first three contactors. The clean product is drawn off the fourth contactor and fed to a plate and frame filter press for dewatering. Spent wash water is drawn off the first contactor for recycling or disposal.

Application

The soil washer has been successfully tested with lead- and phenol-contaminated soils. It is applicable to soils contaminated with soluble organics and heavy metals. An increase of fines in the feed would result in a decrease in throughput.



Source: United States Environmental Protection Agency

Figure D.6
PROCESS FLOW SCHEME FOR USEPA SOIL WASHER

VSEPACH1

State of Development

The technology was originally developed to remove oil from beach sand that had been contaminated by oil spills. It was later modified and used for a full-scale field demonstration in Alabama. USEPA is currently soliciting proposals for the transfer of the technology to the private sector.

HWZ Process

Process Description

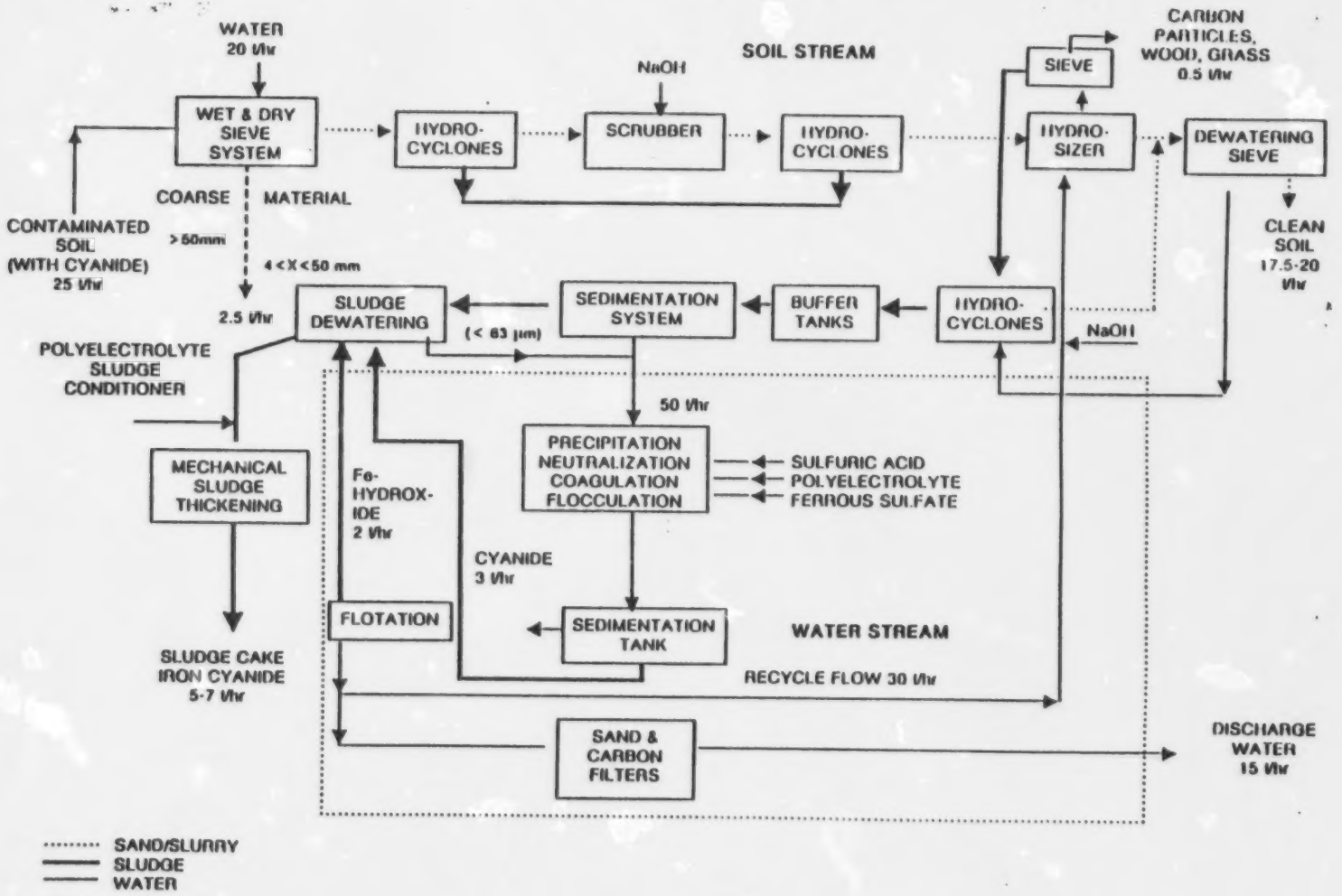
The HWZ process was developed in The Netherlands and is based on techniques of soil washing and particle sizing, along with a water treatment stream. A flow schematic of the system is shown in Figure D-7. After crushing larger pieces of rubble, particles between 4 and 50 mm are separated out by wet sieving. Soil particles between 63 micron and 4 mm comprise the main soil stream. These particles are washed of adsorbed contaminants by scrubbing with detergents and adjusting the pH to between 12 and 13 by the addition of sodium hydroxide. A hydrosizer then removes low density organic and carbon particles. After a dewatering step, the remaining sand (particle size between 63 micron and 4 mm) is often clean enough to be used in asphalt batching or to be landfilled. The fines (less than 63 micron) are separated by hydrocyclones and dewatered in a belt press. This small volume of fines is highly concentrated with contaminants and may require further treatment. Wastewater from the process is treated and recycled or discharged.

Application

Depending on the chemical additives used in the flocculation tank, this system can remove:

1. Complex and free cyanides
2. Heavy metals
3. Aromatics
4. Chlorinated aliphatic hydrocarbons and solvents
5. Chlorinated aromatic hydrocarbons

Pollutant levels and removal efficiencies achievable by soil washing are strongly dependent on the distribution of the pollutants over the different fractions and the presence of soil particles other than sand. Where the amount of fine fractions (less than 63 micron) is greater than 20 percent, the volume reduction of the contaminated soil may not be sufficient to warrant economical treatment.



Adapted from: Brook, H.C.M., written correspondence to J. Hyman of Alliance, March 16, 1988.

Figure D.7

HWZ SOIL TREATMENT SCHEME

CH2MHILL

State of Development

A 20-t/h, full-scale unit is operating in Amsterdam. This technology is not yet commercially available in North America.

Heidemij Process

Process Description

The froth flotation method of soil cleaning was developed out of mining technology and enlarged to a full-scale plant by Heidemij Vitroering of The Netherlands. The first step of the process is wet-screening of the coarse (larger than 4-mm) particles. The resulting slurry (one part soil, three parts water) is conditioned with cleaning agents before entering 10 flotation cells operating in parallel. The contaminated float is skimmed off and the slurry is pumped to wet-scouring tanks for final washing in clean water. The cleaned slurry is dewatered by filtration and the soil is usually returned to its original site. The water in the system is recycled.

Application

The process is reportedly applicable to soils contaminated by a number of materials by making minor adjustments to the process and using the appropriate cleaning agents. These materials include:

1. Oil products
2. Heavy metals
3. Inorganic compounds
4. Aromatic compounds
5. Polycyclic hydrocarbons
6. Chlorinated hydrocarbons
7. Pesticides, herbicides, and fungicides

The process is not economical for treating soils having a fine fraction (less than 50-micron) over 20 percent.

State of Development

The mobile soil washer consists of nine transportable modules that occupy a 950-m^2 area. Rated capacity is 27 t/h.

Oil Cleaning Recycling Environmental Protection (OIL CREP)

Process Description

Oil CREP is a proprietary combination of surfactants, solvents, and aromatic hydrocarbons that extracts oil from various media while preserving the structure of the oil so that it may be recycled. The system was developed in Germany mainly for the remediation of hydrocarbon-contaminated sandy soils (particles larger than 100 microns).

The Oil CREP System SSC-20A is a mobile soil washer that occupies one 6-m container. It was initially built to clean sandy beaches contaminated with oil. A diagram of the system is shown in Figure D-8.

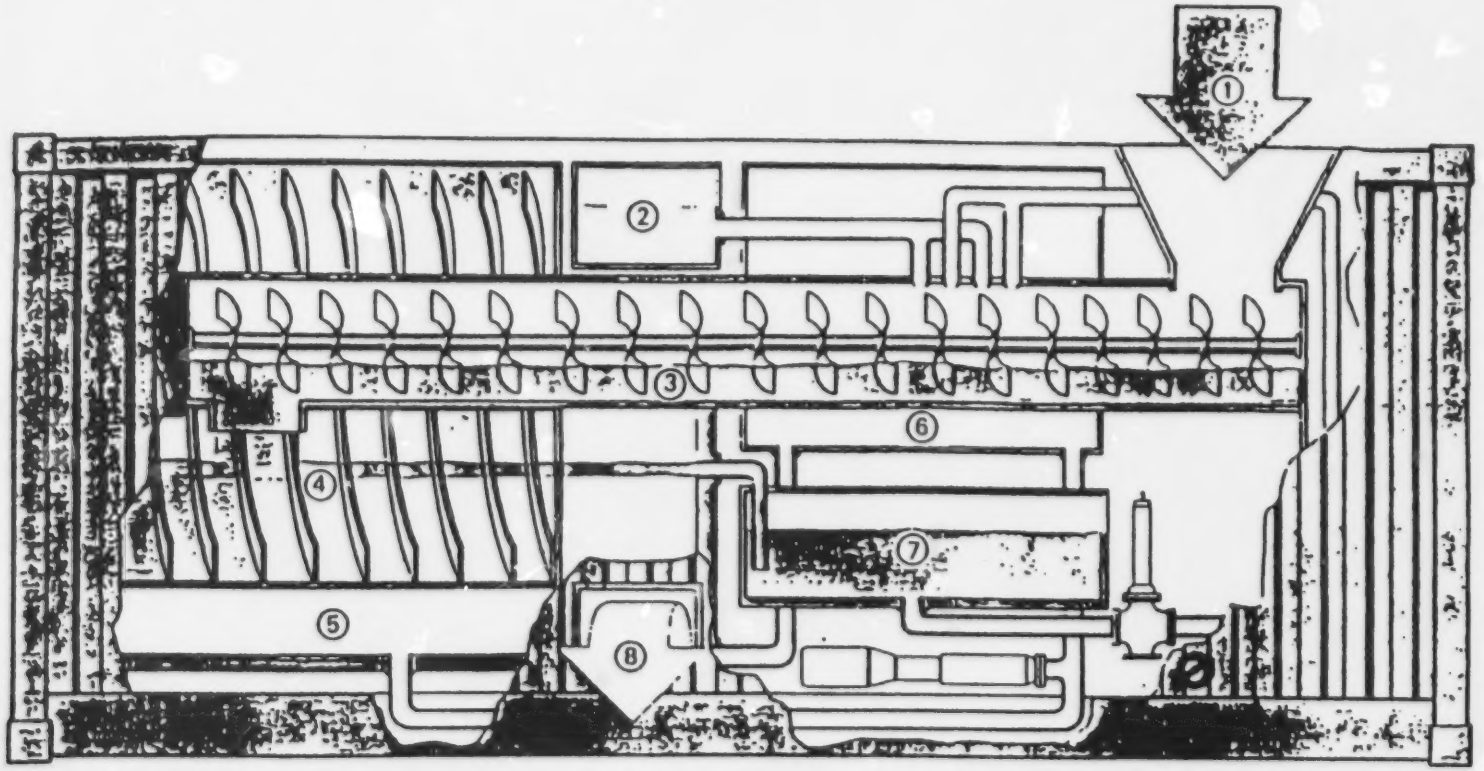
Oil-contaminated sand/gravel no larger than 50 mm is fed into the system via a hopper. A cleaning agent is injected into the sand as it is mixed in a screw mixer. The sand then travels to a rotating separation drum where the oil is floated off the sand using fresh water and spilled over into a collection tank. The cleaned sand is reused onsite. The collected oil and cleaning agent is removed for refining or disposal.

Application

The system is mainly used to clean sandy soils. Where contamination is complex and a large fraction of fines are present, the processing cost is increased and treatment efficiencies decreased. It is applicable to gasoline, crude oil, mineral oil, and other oil products.

State of Development

TBSG, Bremer Vulcan AG, and AEG Marine and Offshore Systems Division jointly developed the Oil CREP System. A prototype unit has an average throughput of 8 m^3/h. A full-scale unit is in the planning stages and is expected to have a throughput of 20 m^3/h.



1 Oil contaminated sand
2 Cleaning agent OIL—CREP I
3 Mixing unit
4 Separation drum
5 Washwater tub
6 Washwater reserve tank
7 Oil collection tank
8 Cleaned sand

Source: Bremer Vulcan AG, et al., "Protection of the Environment, On-the-Spot Cleaning of Oil-Contaminated Sand and Soil, Oil CREP System SSC-20A," undated.

Figure D.8

OIL CREP SYSTEM SSC-20A
MAJOR COMPONENTS

CH2MHILL

Harbauer Soil Washing Technology

Process Description

The Harbauer soil washing system's principal operations are screening, conditioning, contaminated fines removal, soil washing, particle size graduation, and dewatering. The success of the Harbauer soil washing system is primarily attributed to its vibrating unit to remove contaminated components. A flow schematic is shown in Figure D-9.

The first step of the Harbauer system is to screen out large particles (greater than 60 mm) and to remove metallic objects. The screened material is washed by a blade washer before entering the main process stream and is then conditioned with surfactants and extractants to aid in the removal of contaminants.

A screw conveyor delivers the soil to the vibrating unit where the solids are subjected to low frequency oscillations that dislodge the contaminated fines from the soil. The fines are removed from the process in the next step when the soil is washed using a blade washer.

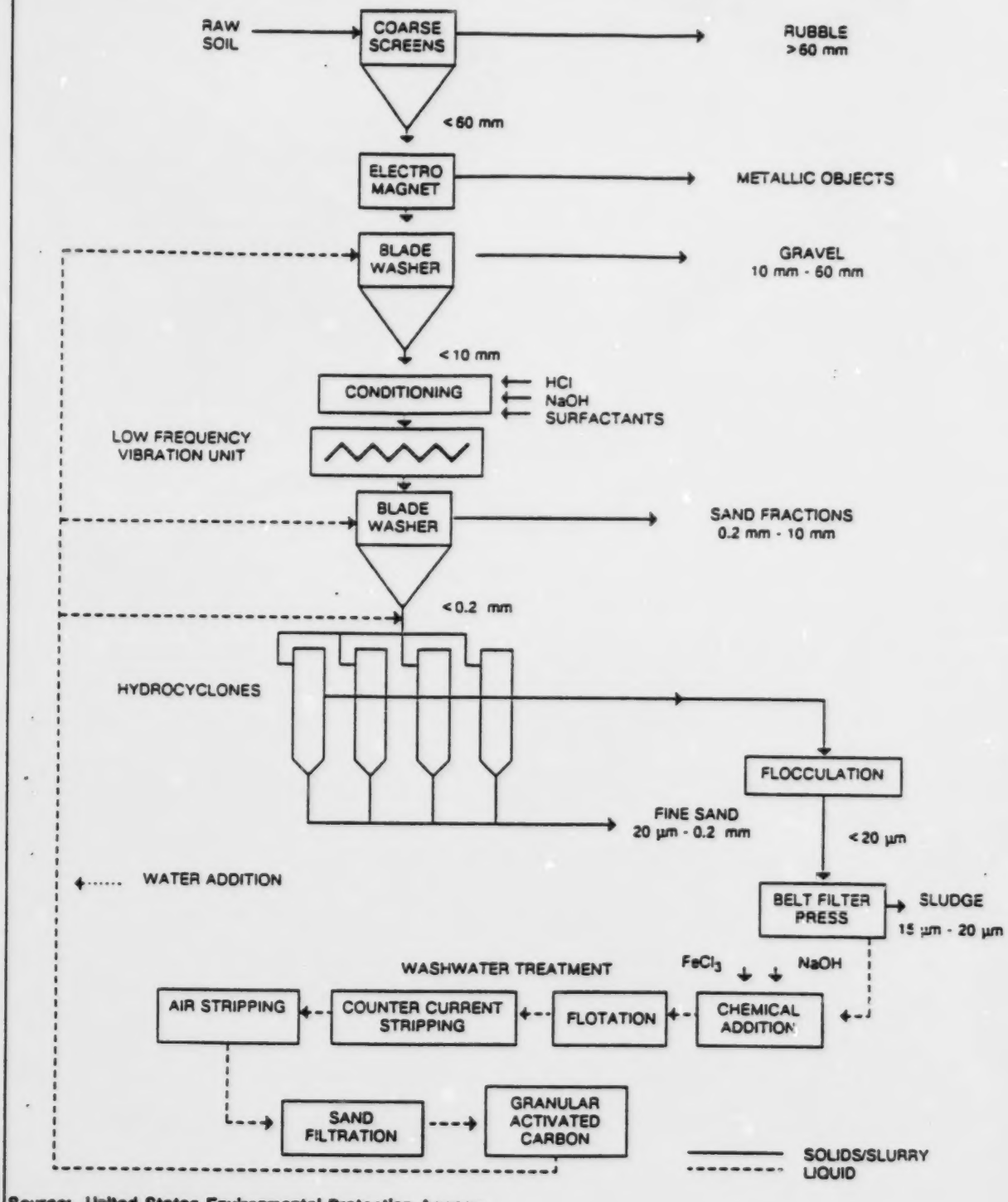
The cleaned soil is then screened and graduated by particle size using sedimentation, hydrocyclones, and flocculation, and is later dewatered using a belt press to reduce the volume of soil to be disposed of in the landfill site.

The contaminated effluent from the soil washing is treated by dissolved air flotation units, countercurrent stripping, air stripping, and filtration and adsorption (activated carbon or ion exchange). The resulting clean water is reused or discharged into a receiving stream.

Application

The Harbauer soil washing system is capable of treating 16-22 t/h of soil contaminated with organics, phenols, organic chloride compounds, and PCBs. There has been limited success in treating heavy metals but data are not yet available. The process can treat both sandy and clay soils (15 microns - 15 mm particle size). A higher residual volume is generated when cleaning clay soils.

Treatment costs for the Harbauer soil washing system are reported to be approximately $170 per cubic metre of waste treated.



Source: United States Environmental Protection Agency

Figure D.9

HARBAUER SOIL WASHING PROCESS SCHEMATIC

CH2MHILL

MTA Soil Wash

The MTA soil wash process is patented by MTA Remedial Resources, Inc. of Golden, Colorado. It uses technologies developed by the mineral processing industry to physically separate the three phases: contaminant, aqueous solution, and sediment particles.

The MTA process essentially consists of four steps: physical preparation of contaminated soils; reagent addition and agitation; flotation; and dewatering of froth solids and clean soil.

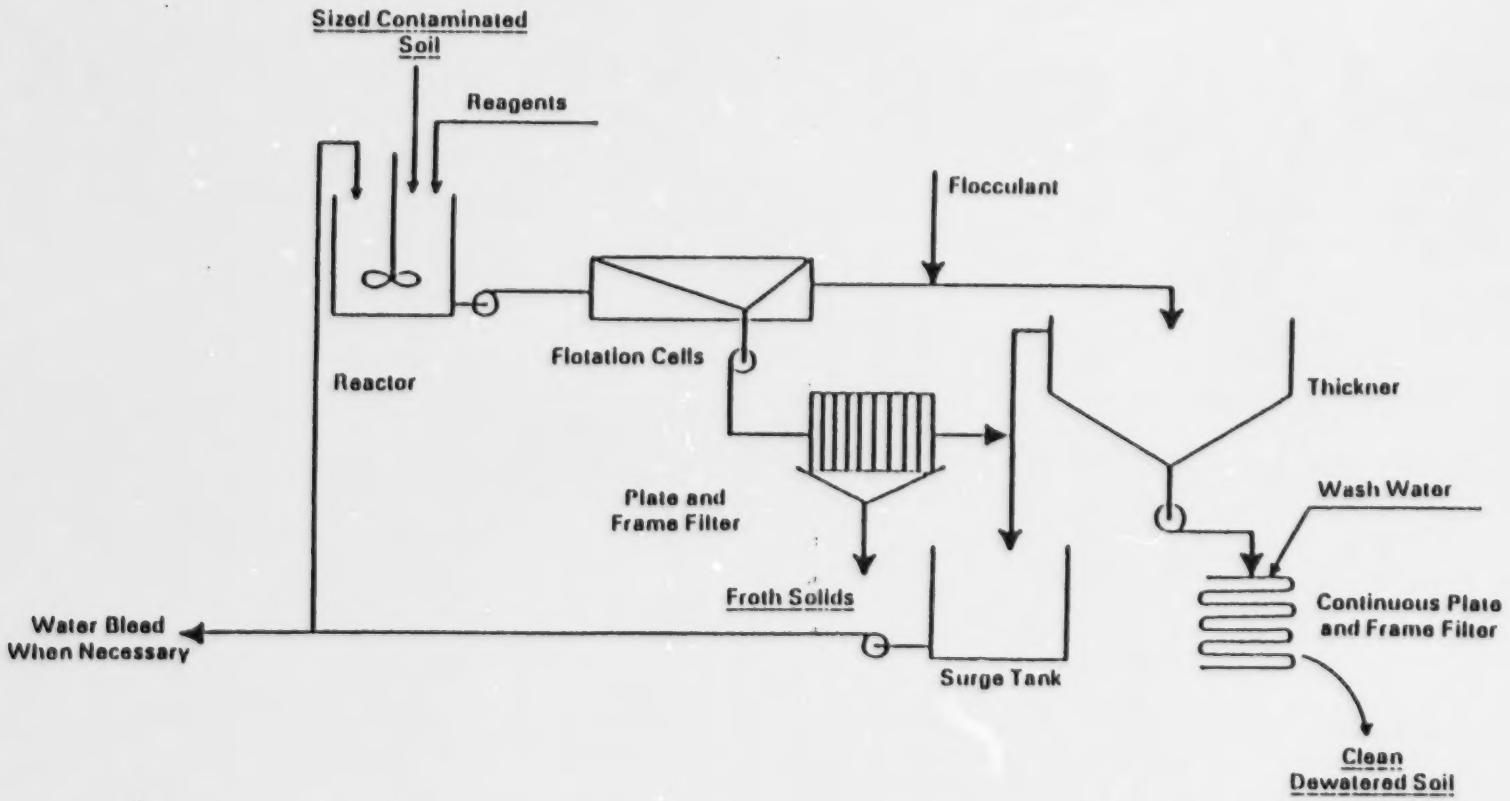
Figure D-10 presents a schematic of the MTA process. The first step involves the proper sizing of the contaminated soil to provide a consistent feed to the process equipment. In the second step, water and reagents are added to and mixed with the sized feed. The flotation step causes the now desorbed and hydrophobic contaminants to preferentially attach to the small air bubbles in the agitated and aerated slurry in the flotation cell. These air bubbles rise to the top of the flotation cell and form a froth. This froth is skimmed off the liquid. The cleaned solids are drawn out of the flotation cell as a continuous underflow. The froth and the cleaned soil are directed to filter presses for dewatering.

Application

The vendor claims the technology can be used to liberate and mobilize organic compounds from sand and clay particles.

State of Development

Only bench-scale treatability testing has been performed on tank bottom and pond bottom sludges.



Source: Electric Power Research Institute, July 1987, "Remedial Technologies for Leaking Underground Storage Tanks"

Source: MTARRI

Figure D.10

MTA SOIL WASHING SCHEMATIC

CH2MHILL

Hot Water Extraction Process

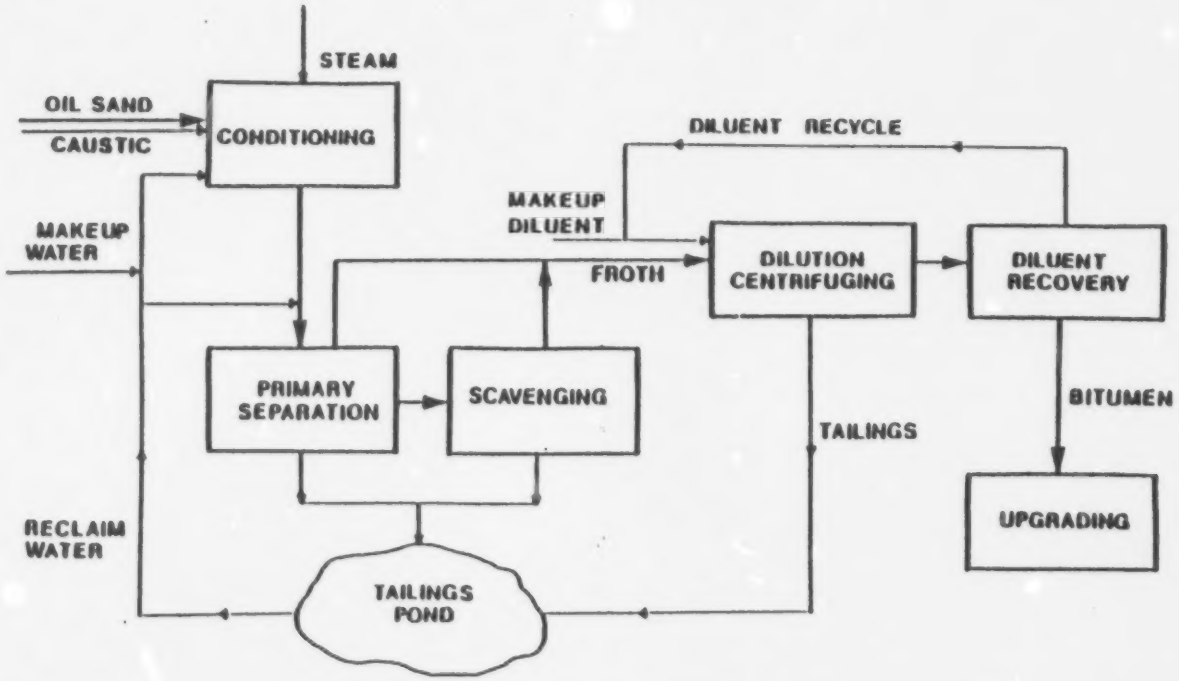
Process Description

In this process, oily material such as mined tar sands is mixed in large rotating conditioning drums with steam, hot water, and sodium hydroxide at approximately 80°C. Lumps are reduced to slurry by ablation. Sodium hydroxide or another base is critical to the process and apparently acts to alter interfacial tensions, which results in more efficient separation of bitumen. Other important parameters in this process are the oil-sand-to-water ratio, temperature, residence time, and mechanical energy input.

Effluent from the conditioning drum is screened to remove undigested material, additional water is added, and the mixture is fed to the primary separation cell. This cell is a gravity settler where the solids sink and the bitumen rises to the top. A third output, middlings that consist of bitumen, solids, and water, is withdrawn and fed to air flotation cells which are effective in scavenging the bitumen. The resultant froth is cleaned, deaerated, and combined with the primary cell froth and further deaerated to yield the hot water process froth. This is subjected to further bitumen extraction through the addition of naphtha (approximately 5 percent) and centrifugation in a two-stage operation, each stage consisting of multiple centrifuges of conventional design installed in parallel. The purified bitumen is withdrawn and the naphtha recovered and recycled. The bitumen then passes on for upgrading (see Figure D-11).

Applications

The Hot Water Process for extraction of bitumen from oil sands was first described by Dr. Carl A. Clark in the 1930s and 1940s. Clark discovered that sand in the ore is water-wet and that the oil is essentially isolated from it by a thin film of water. Bitumen extraction using this process is practised at the only two oil sands mining facilities in the world, Suncor and Syncrude in Alberta.



Source: Tricil Limited

Figure D.11

PROCESS FLOW DIAGRAM FOR HOT WATER EXTRACTION PROCESS

RTROSA/Gulf Process

Process Description

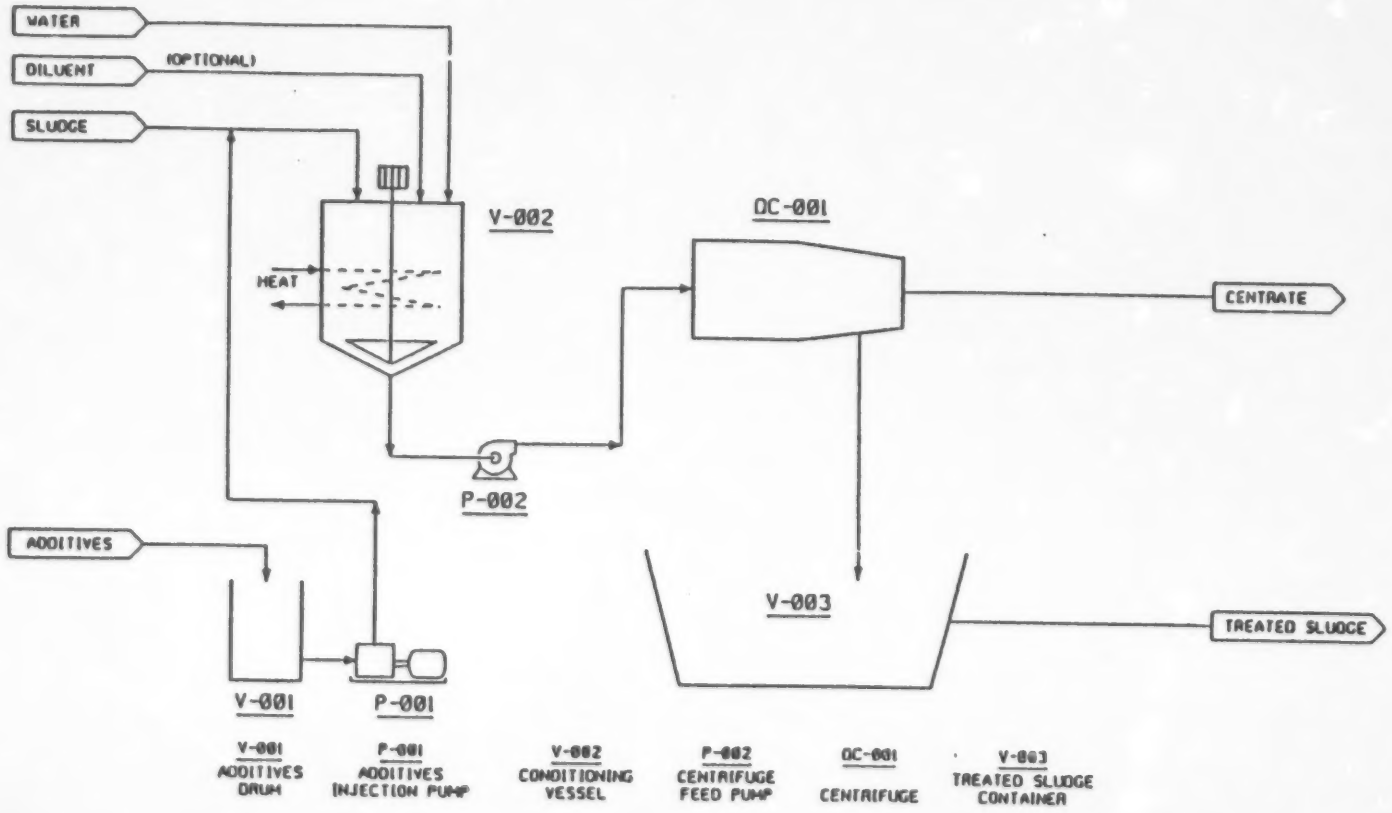
A process was developed by RTR Oil Sands (Alberta) Ltd. (RTROSA) and Gulf Canada Corporation (Gulf) for the removal of hydrocarbons from clay-based sludges. The process is intended as an upstream separation unit of a more complete treatment system.

Figure D-12 presents a flow schematic of the process. The first step involves conditioning the raw sludge with modifiers of surface tension, wetting agents, etc. If the density and viscosity are outside workable limits, a diluent along with water is added. The raw sludge mixture is retained at a temperature of 45 - 60°C in the conditioning vessel for about 5 seconds.

The conditioned sludge is fed to a solid bowl centrifuge for phase separation. A two- or three-phase centrifuge may be used, depending on the hydrocarbon characteristics and on the specific application. The hydrocarbon-to-solids mass ratio is inversely proportional to the flowrate. The centrifuge process produces a sludge cake with a moisture content of 20 - 30 percent that can be subjected to final reclamation using conventional techniques. The liquid centrate consists of most of the hydrocarbon and water that was present in the raw sludge. A small amount of solids may also be present.

Application

Experimental pilot-scale tests using a continuous process have been carried out on sludges with 25 - 40 percent by weight hydrocarbons. Treated sludge having a hydrocarbon content less then 5 percent by weight was achieved.



Source: RTR Oil Sands (Alberta) Ltd.
Gulf Canada Resources Ltd.

Figure D.12

RTROSA/GULF SLUDGE CONDITIONING PROCESS SCHEMATIC

CH2MHILL

D.3 THERMAL TREATMENT

Rotary Kiln Incineration

Description

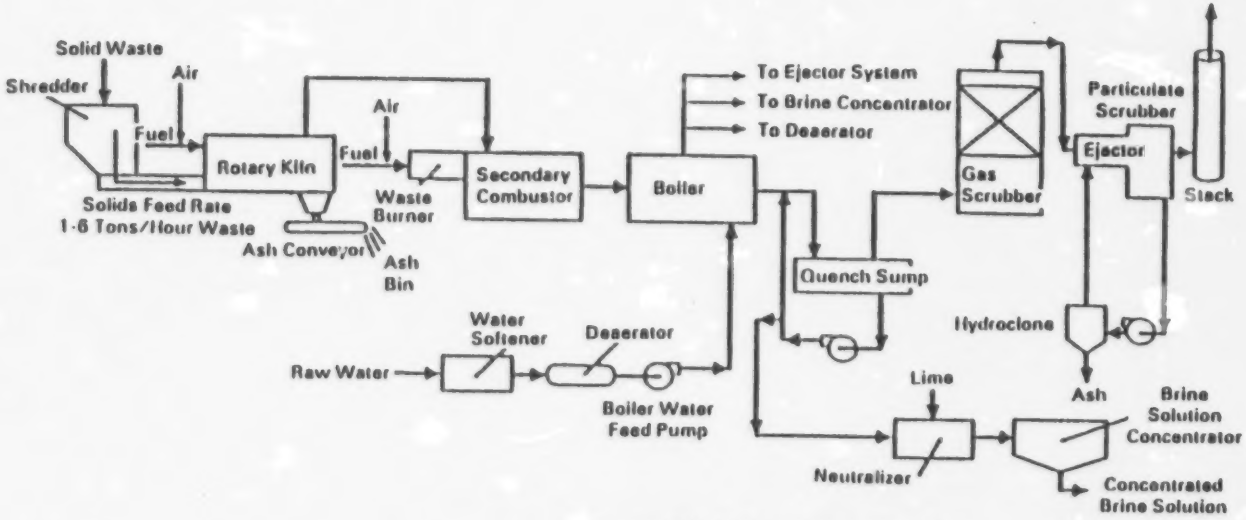
Contaminated soil is fed to the kiln on a belt conveyor. The rotary kiln is a refractory-lined, steel cylinder mounted on rollers at a slight angle from the horizontal. It rotates as the wastes are injected into the higher front end of the kiln. Fuel for firing the kiln is introduced, producing temperatures that range up to 1100°C. Residue is continuously discharged from the lower end of the kiln while gaseous combustion products exit into an afterburner chamber to complete oxidation of the combustible gases. The gases are then cooled and scrubbed before exiting the stack. Figure D-13 shows the process schematic for a rotary kiln.

Rotary kilns are available as mobile units that can be leased for short-term use onsite or transportable units purchased for long-term installation onsite. Mobile units are typically used for cleanups requiring 12 months or less and transportable units are designed for a site cleanup effort in the range of 1 to 5 years.

Application

Most organics are potential candidates for incineration in rotary kilns. Inorganic or inert materials, however, are unlikely or difficult candidates; this includes lime/clay mixtures with adsorbed solvents, resins and wastes containing inorganic salts that will result in refractory attack or slagging, and heavy metals which will result in high flue gas emissions and a residue containing heavy metals. Fine particle sizes such as clay or silts will result in high particulate loading in flue gases due to the turbulence in the rotary kiln. Spherical or cylindrical wastes may roll through the kiln before complete combustion can occur. Oversize debris must be crushed and shredded before feeding the kiln.

Process residuals include bottom ash/soil, fly ash, scrubber liquor, and off-gases. The solid residue may contain residual heavy metals and would require further treatment prior to disposal.



Source: ENSCO Environmental Services

Figure D.13

ROTARY KILN INCINERATION PROCESS SCHEMATIC

The rotary kiln, both fixed and mobile, is a well established, commercially available process for the treatment of wastes.

One of the first commercial cleanups of a contaminated site by incineration was at Sydney Mines near Tampa, Florida. The kiln system was designed, constructed, and operated by ENSCO Pyrotech of Little Rock, Arkansas.

A mobile rotary kiln incinerator was installed at an old oil and solvent storage/transfer site in Chicago, Illinois, in 1987 June. High concentrations of oils, petroleum products, and chemical constituents in addition to chlorinated compounds were detected in the solids, sludges, and liquids onsite. Since then, 7000 tons of soil have been incinerated.

Infrared Incineration

Process Description

An infrared system developed by Shirco Infrared Systems, Inc. treats waste by metering the waste stream onto a conveyor belt and passing the waste under infrared heating elements exposing it to irradiation. Combustible off-gases are burned in a secondary chamber which can either be a gas-fired/infrared unit or a conventional secondary chamber.

The unit tested was a portable system that was contained on a 14-m trailer. The primary chamber was rectangular and was lined with multiple layers of ceramic fiber blanket insulation. Infrared energy was provided by heating elements along the entire length of the furnace. The secondary chamber was equipped with a propane burner and was sized to provide a gas residence time of up to 2.2 seconds. Scrubbers were provided for off-gas cleanups.

The waste fed to the process must be homogeneous in size and have a moisture content greater than 22 percent to allow proper conveyance.

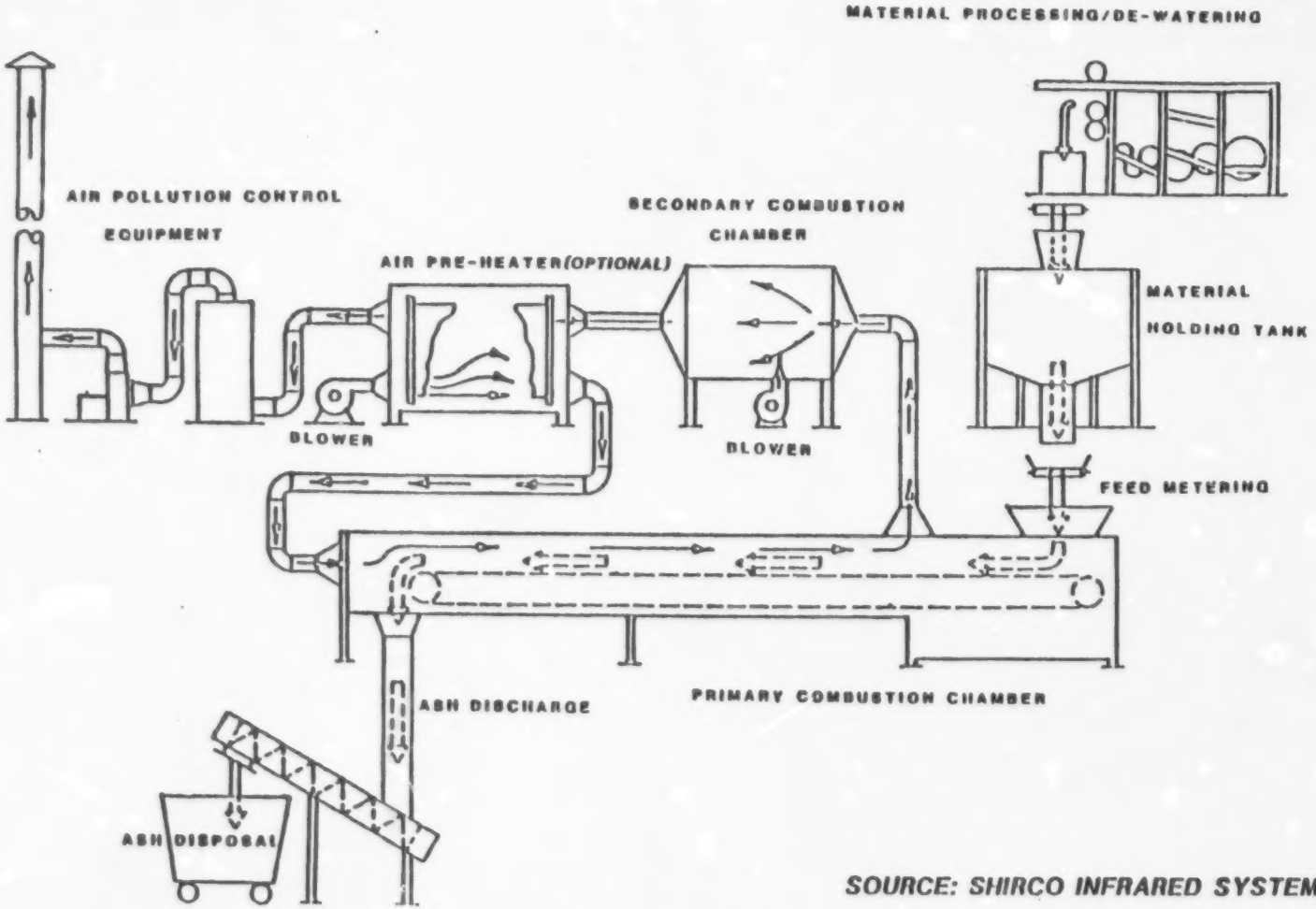
The residuals from this process, like those of other thermal processes, are ash, scrubber waste, and off-gases. The solid residue should be tested for heavy metals and, if present, would require further treatment before disposal.

A process flow diagram of an infrared incineration system is presented in Figure D-14.

Application

The Shirco Infrared Incinerator has the potential for treating contaminated soils containing dioxins and other organics. It may also have applications for other contaminants subject to thermal destruction.

The application of infrared incineration as a mobile technology has a limited operating history; however, there are a number of fixed infrared units that have been constructed. These units have primarily been used in industrial applications. The only mobile unit being applied to hazardous waste was a pilot-scale system operated by Shirco Infrared Systems Inc.



SOURCE: SHIRCO INFRARED SYSTEMS INC.

Figure D.14

PROCESS FLOW DIAGRAM OF INFRARED INCINERATION SYSTEM

Molten Salt Incineration

Process Description

Shredded solid waste is mixed with air and fed to a reactor containing a bed of molten salt (e.g., sodium chloride, sodium sulphate, sodium carbonate) which is maintained at temperatures of 800 to 900°C. Gaseous products, neutralized in the caustic environment of the reactor, are separated from entrained solids and particulate matter, then discharged. Bed materials are tapped from the reactor, cooled, and landfilled.

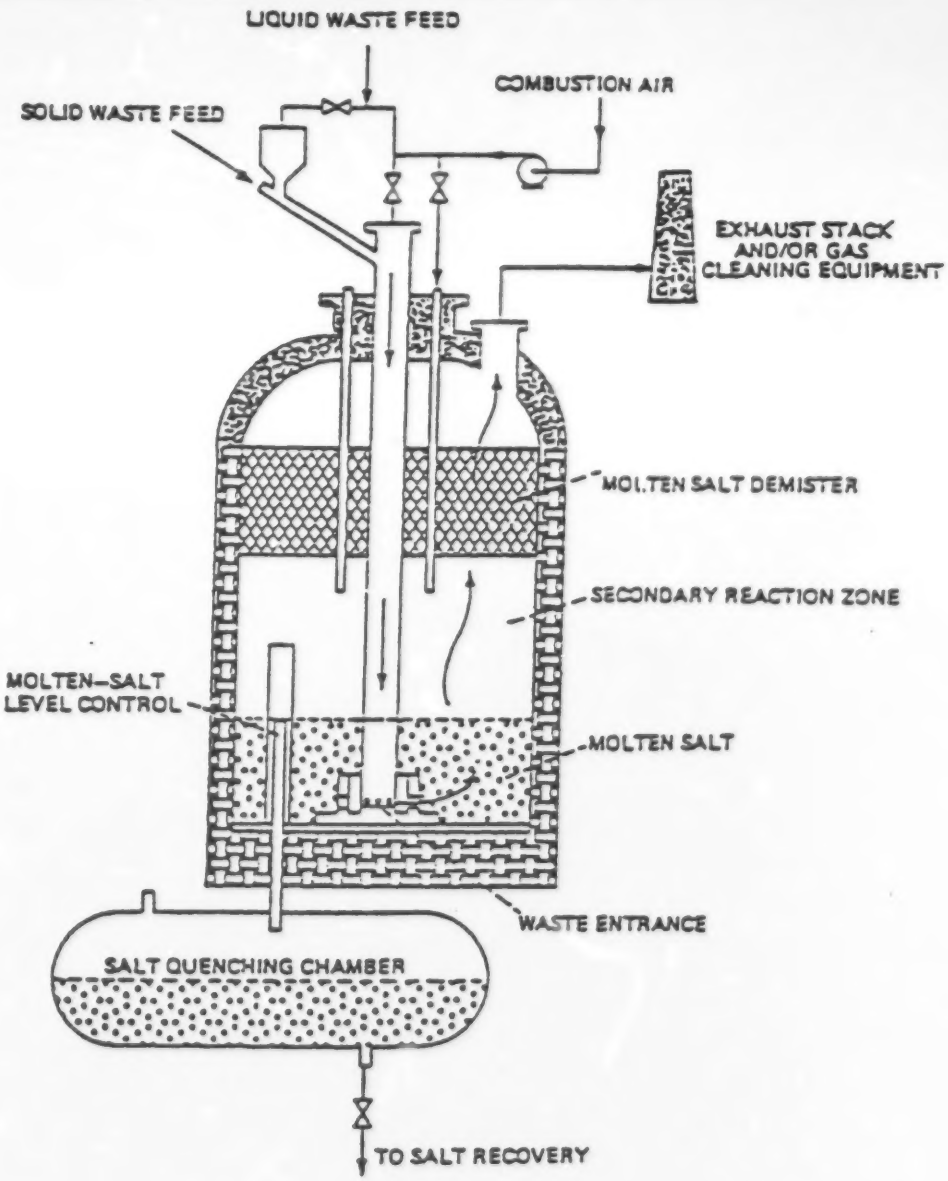
The molten salt incinerator is a refractory-lined vessel in which the shredded waste is injected. Auxiliary equipment includes a baghouse through which the off-gases pass to separate the particulate matter prior to exhausting to the atmosphere. An air supply for combustion is required. Additional fuel may be required when wastes do not have a sufficient heat content to maintain combustion temperatures. A schematic of a typical molten salt incinerator is presented in Figure D-15.

Application

Molten salt reactors are designed for solid and liquid wastes, especially highly toxic, inorganic, or halogenated compounds. The technology has been demonstrated to be highly effective for chlorinated hydrocarbons including PCBs, chlorinated solvents, and malathion. This technology is generally not suitable for wastes with greater than 20 percent noncombustible ash or with aqueous wastes.

Byproducts include spent molten salt containing ash and particulates from the air-emissions-control baghouse.

Pilot-scale units have been developed and tested; however, the process is still in the experimental stage.



Source: United States Environmental Protection Agency, October 1986, "Treatment Technologies for Dioxin-Containing Wastes"

Figure D.15

SCHEMATIC OF GENERALIZED MOLTEN SALT INCINERATOR DESIGN

Fluidized Bed Incinerator

Process Description

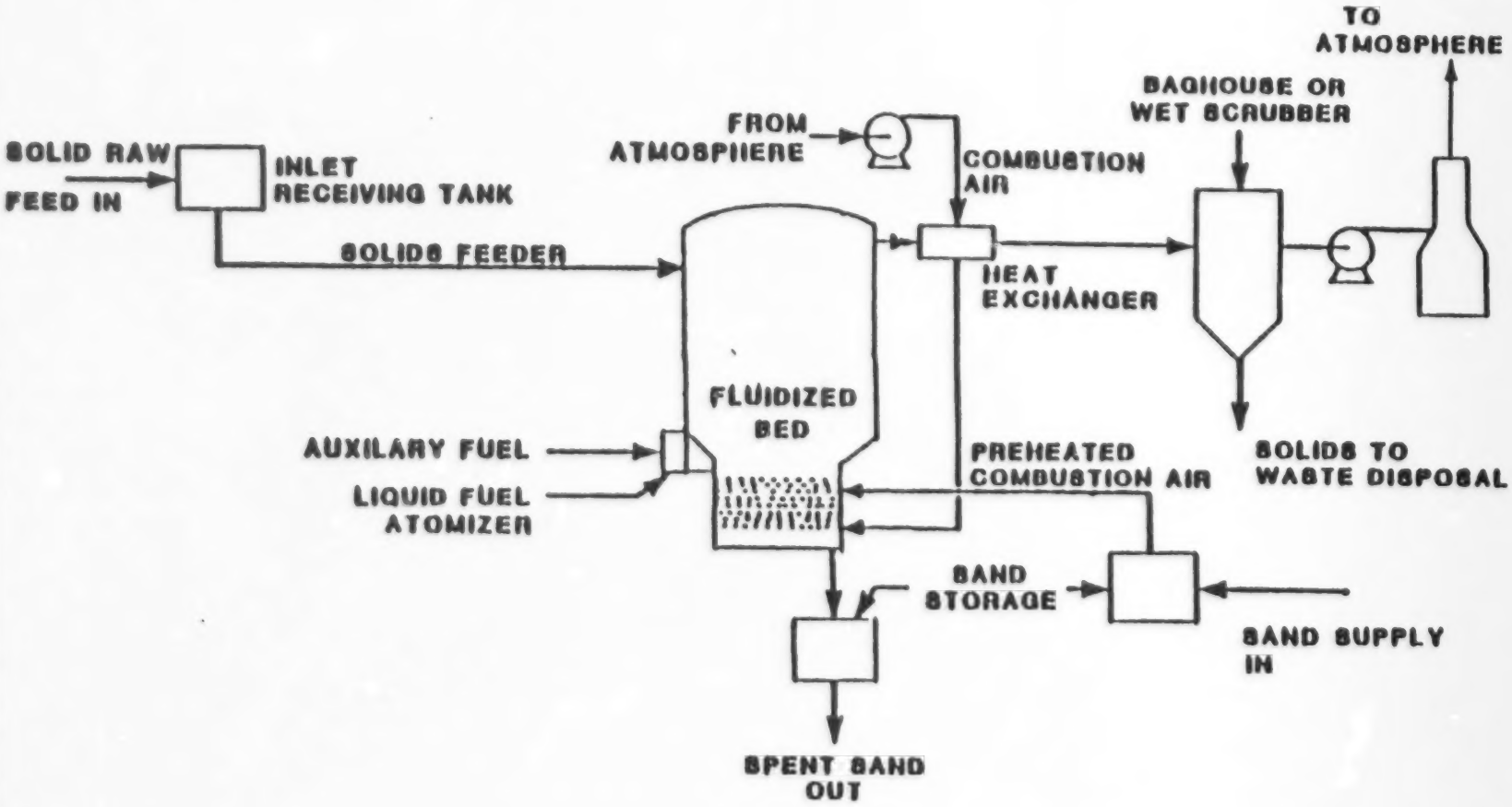
A fluidized bed incinerator is a vertical, refractory-lined, steel structure containing a bed of inert granular sand-like material. The inert material, usually sand, is fluidized by the injection of air into the bottom of the bed through a perforated plate. Once the bed is heated to the correct operating temperature for combustion, liquid or solid waste is injected into or above the bed. Supplementary fuel, to maintain combustion, is fed directly into the bed or above the bed, and/or is fired in the windbox. The heat of combustion of the waste, fuel, and hot bed material in the presence of fluidizing air provides a combustion environment that resists fluctuations in temperature and retention time due to moisture, ash, or Btu content of the waste.

A secondary reaction chamber allows sufficient retention time to allow for complete combustion of volatiles before being treated for acid gas and particulate constituents. Combustion product gases are scrubbed before release to the atmosphere.

A variation of fluidized bed technology is circulating bed combustion. The circulating bed system increases turbulence by the use of high air velocity, creating a larger combustion zone and a larger retention time. This allows incineration at lower temperatures (800 - 870°C) and as a result eliminates ash agglomeration and reduces nitrous oxide emissions. Because of the high air velocity, solids are entrained and combustion takes place along the entire height of the combustion section, thus increasing throughput per unit area.

The entrained solids are separated from the off-gases by an integral cyclone and recycled to the combustor. The flue gases are cooled and any remaining particulates in the cooled off-gas are separated in a baghouse filter. The clean off-gas stream is then vented to the atmosphere.

Fluidized bed incinerators are available as either fixed commercial systems or mobile systems. To date, most fluidized bed and circulating bed systems handling hazardous wastes are fixed facilities. Figure D-16 is a process flow diagram of a fluidized bed incinerator.



Source: EPA Report No. 540/2-86/003 September 1986, "Mobile Treatment Technologies for Superfund Wastes"

Figure D.16

PROCESS FLOW DIAGRAM OF FLUIDIZED BED INCINERATOR

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Application

Granular solids, sludges, slurries, and some liquids can be treated with this system. Particular wastes that may be processed are contaminated soil, halogenated organics, nonhalogenated organics, PCBs, and phenolic wastes. This process is not well suited for large, irregular, or noncombustible solids; wastes that can fuse the bed, e.g., wastes containing salts; or wastes with a high heavy metal content which will result in volatization of metals and unacceptable emission levels. Pretreatment, such as grinding and size reduction, is required to provide a uniform feed.

Process residuals include bottom fly ash, scrubber liquor, and off-gases.

Conventional fluidized bed systems have had many industrial uses in the last 80 years. However, there are only a few full-scale fixed systems used to destroy hazardous wastes. As of 1988 September, at least one commercial mobile unit has been constructed and others are planned for construction.

High Temperature Slagging Incineration (HTSI)

Process Description

High temperature slagging incineration is a volume reduction technique which transforms waste into a mechanically strong and chemically stable, basalt-like material in granules or bulk form.

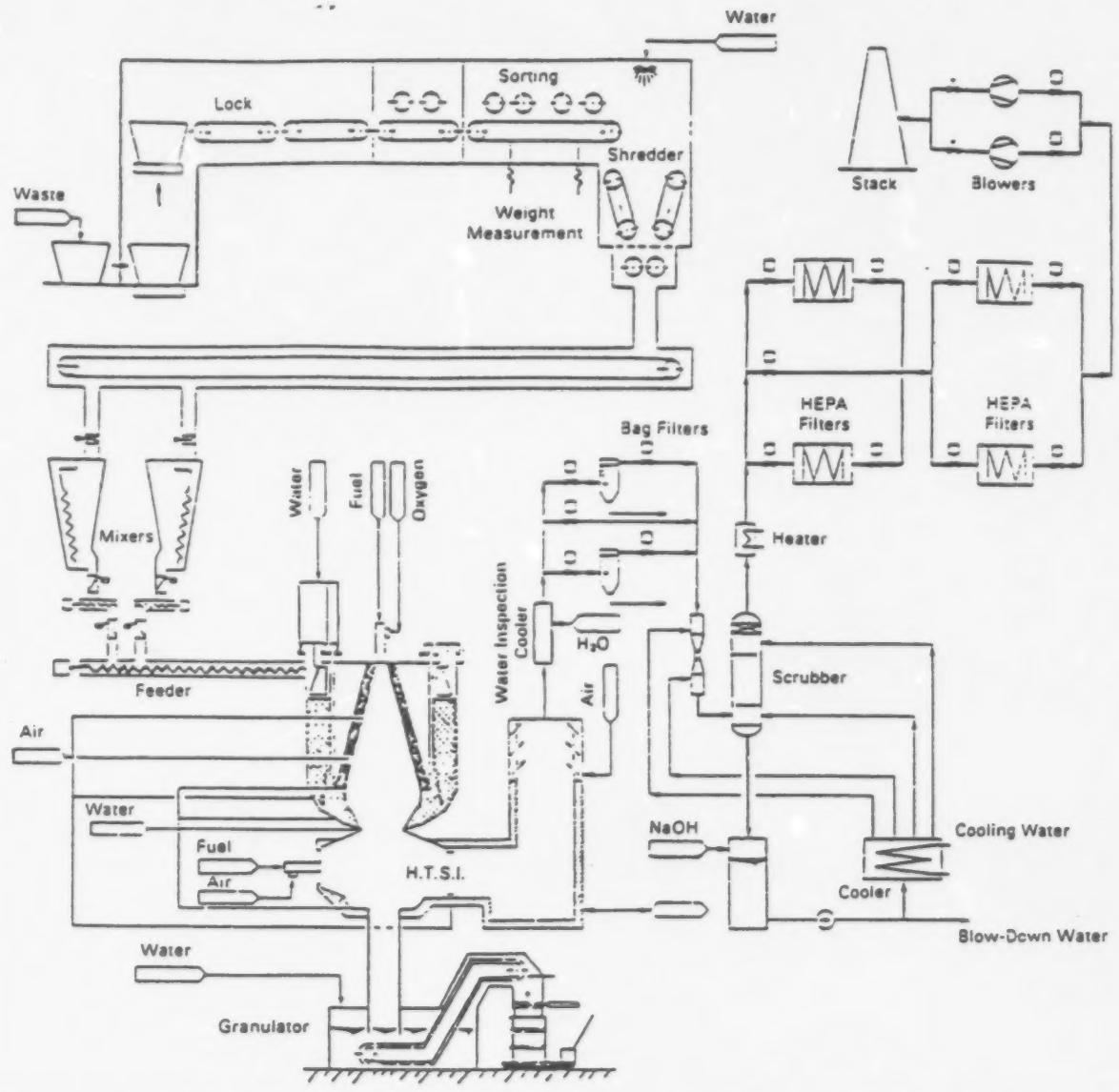
The principal operations are waste shredding and mixing, combustion into molten slag, slag granulation by quenching, and off-gas treatment. A schematic of the HTSI process is shown in Figure D-17.

In the first step of the process, the wastes are sorted, shredded to 7 cm, and mixed in large bins to create a homogeneous stream. Screw conveyors then carry the waste to the combustion chamber of the HTSI unit where the outer layer of waste melts to produce a layer of molten slag. The inner layers of wastes pyrolyze whereas the outer layer of molten slag oxidizes.

The molten slag droplets flow off the bottom end of the refractory bell into a granulator where granules are formed as the slag droplets are quenched. At the same time, the off-gases produced are directed to the off-gas treatment section which consist of a post-combustion chamber, teflon bag filters, scrubber unit, and HEPA filters.

Application

The HTSI process is commercially treating low-level radioactive wastes in Belgium and in Japan, but the process is limited by its low capacity and high costs. Experimental test runs have been performed with some success in the destruction of PCBs. Due to its high costs, HTSI would likely find applications limited to highly hazardous wastes (dioxins and PCBs) and fibrous asbestos waste.



Source: Vanbrabant, R., and N. Van de Voorde. "High Temperature Slagging Incineration of Hazardous Waste." 2nd International Conference on New Frontiers for Hazardous Waste Management Proceedings. Pittsburgh, PA. p. 42. September 27-30, 1987.

Figure D.17

HTSI INCINERATION PROCESS SCHEMATIC

Westinghouse Pyrolyzer

Process Description

A prototype pyrolyzer built by Westinghouse Environmental Services in Madison, Pennsylvania, uses electrical energy to heat and dissociate the hazardous organic molecules in the solids and sludges which then recombine into simpler molecules. The inorganics are incorporated into a glass matrix producing nonhazardous residue. Figure D-18 illustrates the electric pyrolyzer process in a block diagram form.

The solids are fed into the top of the reactor by the solid feed system which consists of a bucket elevator, volumetric screw feeder, rotary valve, and slide valve. The bucket elevator lifts the solids into a hopper above the volumetric feeder. The volumetric feeder is used to regulate the solid feed to the reactor and discharges the solids into a rotary valve which minimizes the amount of air leakage into the reactor. A slide valve provides a mechanical means to shut off the solid feed system and isolate the pyrolyzer to prevent gas leakage into or out of the reactor.

The reactor is constructed in two sections: the upper dome portion and the lower tub portion. The dome contains the heaters and the tub contains six electrodes which pass electric current through the molten material to create heat from electrical resistance.

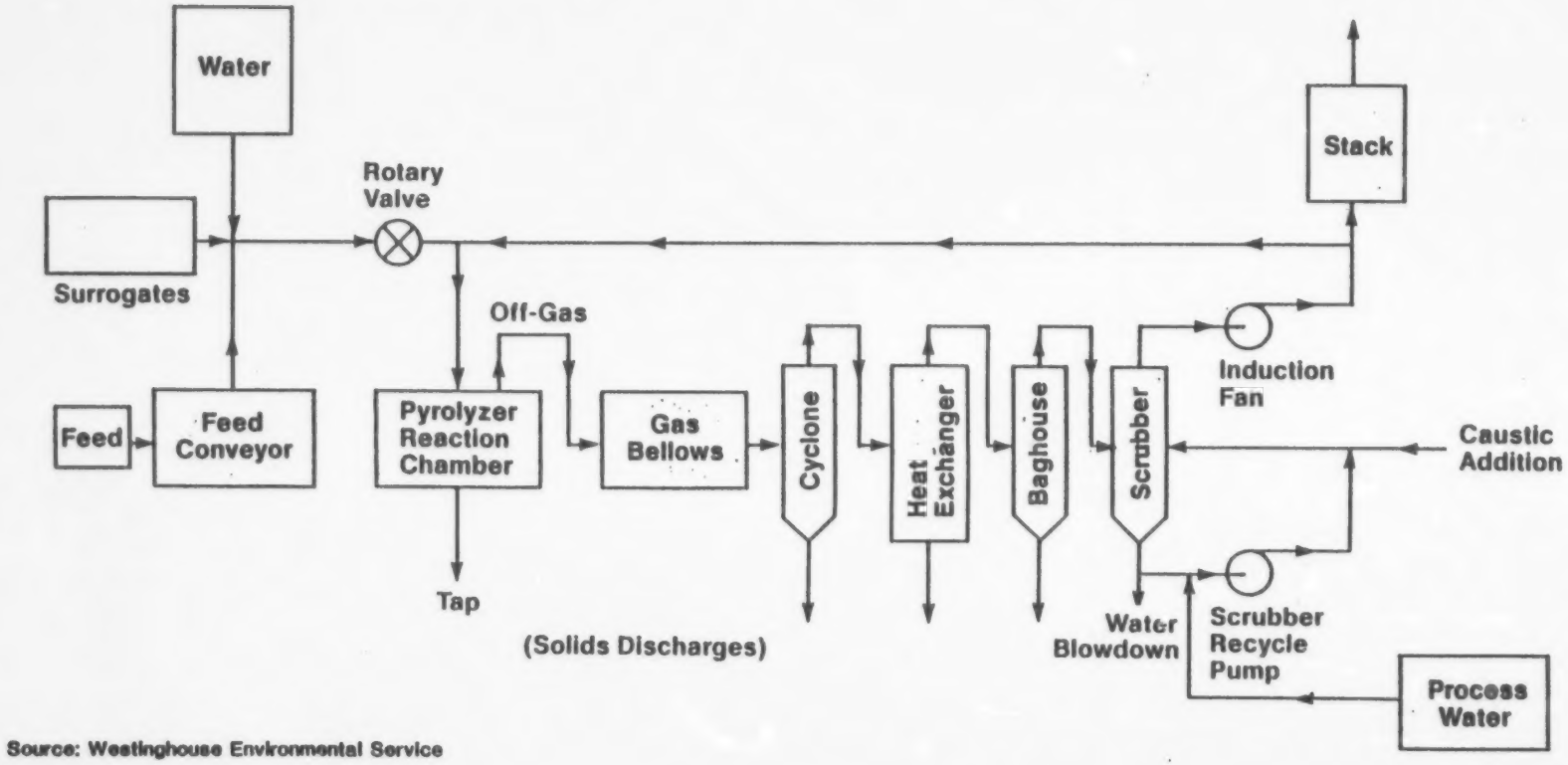
This process takes place in any oxygen-deficient atmosphere. The heat generated by the electrical energy melts the nonvolatile substances and forms a glass-like material at the bottom of the reactor.

The molten solids flow through a throat at the base of the reactor and are then cooled to form a nonleachable solid.

The gases generated in the pyrolyzer are withdrawn by an induced draft fan and pass through several treatment processes before discharge.

Application

The pyrolyzer unit is in the pilot phase and requires further design/engineering to increase the size and throughput. The prototype has a throughput of 6 - 17 t/d.



Source: Westinghouse Environmental Service

Figure D.18

ELECTRIC PYROLYZER PROCESS BLOCK DIAGRAM

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The process has treated PCB-contaminated soils and sludges as well as other hazardous organics. Petroleum production wastes have not been processed through this unit.

The pyrolyzer unit is transportable and easily mobilized to a field site. All equipment is contained on two tractor trailers.

The unit requires 480-volt, 3-phase power and water and sanitary sewer hookup.

TACIUK Processor

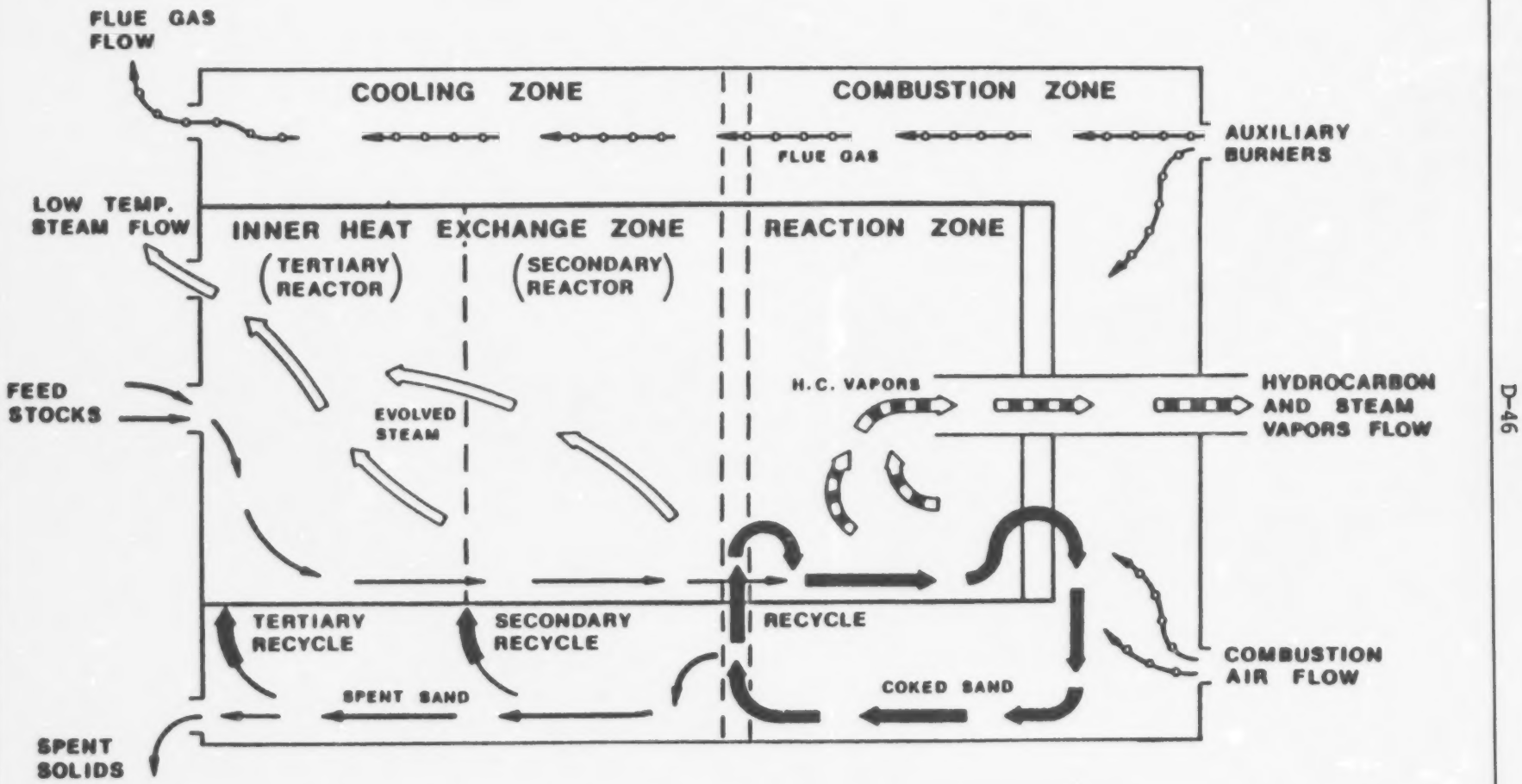
Process Description

The TACIUK processor consists of a single, horizontal, rotating vessel which contains individual compartments that perform the processing steps required to separate various product streams, such as hydrocarbon vapours, spent solids, flue gas, and low temperature steam.

As shown in Figure D-19, sludge/solid feed is introduced into the preheating section of the processor where the water from the sludge is evaporated as steam. Oversized material is removed and solids are heated by heat exchange with the hot, outgoing tailings sand. The preheated sands are then transferred into the reaction zone where they are mixed with hot sand from the combustion zone. The resulting temperature is adequate to thermally crack the hydrocarbons, yielding a vapour stream containing the cracking reaction gases and liquids (in vapour form), and leaving a coke residue on the sand. The vapour stream is passed through cyclones upon leaving the processor to remove fine solids, then processed through a fractionating tower where liquid fractions may be separated for further processing.

The fractionator off-gases are further cooled to condense light ends and water, then passed to a central gas processing plant to recover additional light ends. A heavy bottoms oil cut from the fractionating tower can be recycled back to the processor reaction chamber or used as supplemental process fuel. The product oils can be pumped to downstream or remotely located hydrotreating facilities or sold as fuel.

The coke-coated sand leaving the reaction zone discharges into the combustion zone. In this zone, preheated air is injected to burn most of the coke, which provides heat for the processor. Auxiliary burners are available to provide heat for startup, trim control, and emergency conditions. The hot sand from the combustion zone passes through a recycling zone while allowing hot sand to move into the outer heat exchange compartment. As the hot sand flows through the heat exchange zone, it is cooled by giving up heat to the incoming oil sands



Source: UMATAC Industrial Processes

Figure D.19

TACIUK PROCESSOR MAJOR ZONES AND FLOW STREAMS

CHEMHILL

feed in the preheating section. The partially cooled tailings sand is removed from the processor and can be further cooled and wetted by water prior to disposal.

Combustion gases leaving the processor flow through cyclones, which reduce the fine solids in the gas stream. The gases then pass through scrubbers that remove most of the remaining fine solids and most of the sulphur dioxide produced by combustion of coke. The wet scrubber liquid can be used as a coolant for the tailings sand.

The TACIUK system requires a number of auxiliary systems connected to the processor, including:

1. Feed system
2. Low temperature steam system
3. Hydrocarbon vapour system
4. Flue gas system
5. Combustion air and auxiliary burner systems
6. Cooling system for dry tailings
7. Heat exchange systems

Figure D-20 shows the external systems of the TACIUK process.

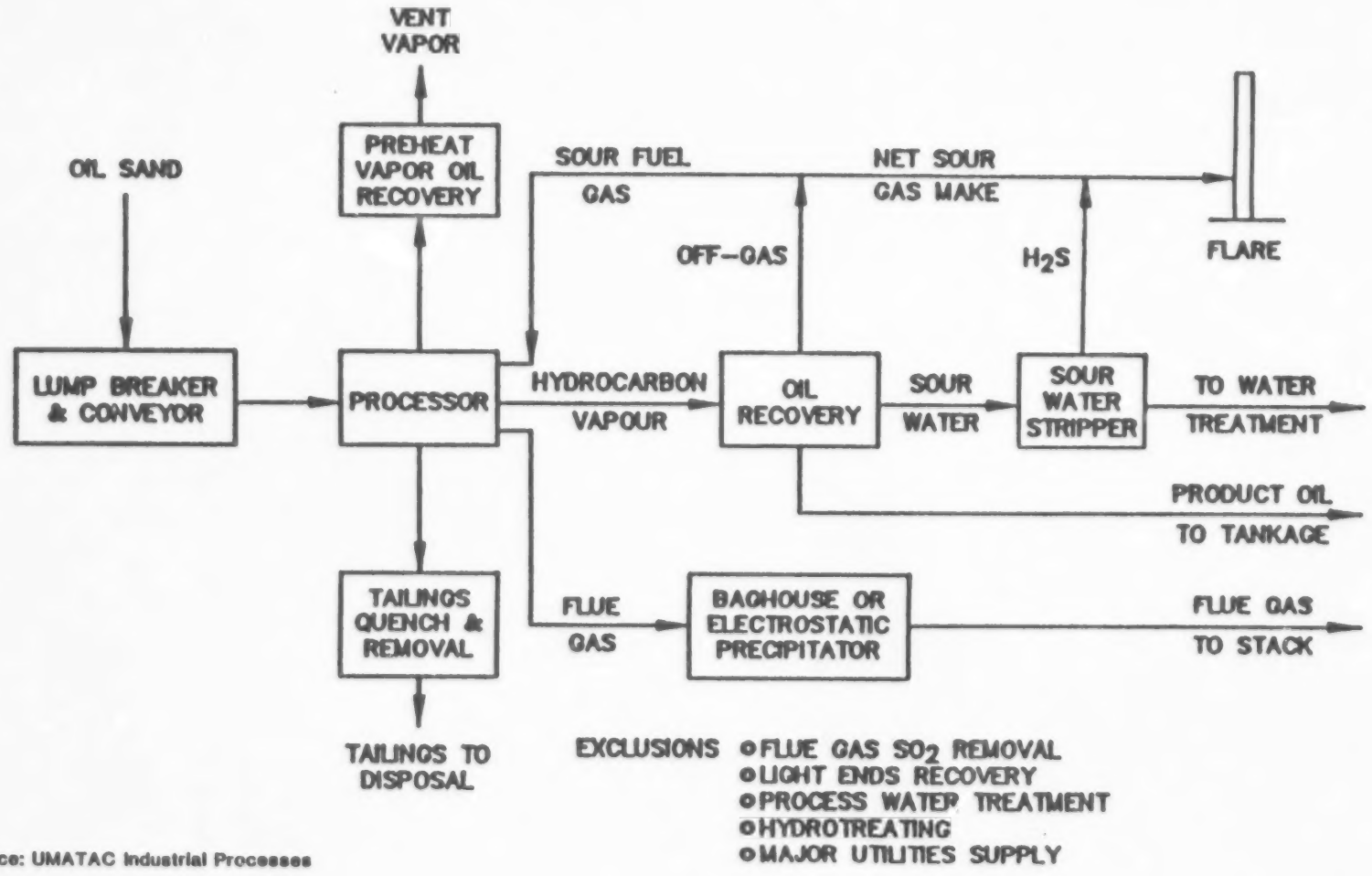
Application

The TACIUK Processor is capable of processing a wide range of oily material to achieve a good yield of oil from the feed. Specifically, feed materials that have been successfully processed in the pilot plant range from 4 - 14 percent oil sands, oil shales, and heavy oil sludge pit materials.

The TACIUK Processor has demonstrated its ability to provide high oil recoveries through pilot runs at a 100 t/d pilot plant.

The process equipment can be manufactured for fixed or mobile applications. Though not yet commercially available, fixed unit design capacities range from 4.5 - 20 t/hr and mobile units range from 4.5 - 12 t/hr.

The TACIUK Processor is now being marketed/demonstrated under the new name of AOSTRA/UMATAC Processor. AOSTRA has built a 10+/hr unit and is now available for testing.



Source: UMATAC Industrial Processes

Figure D.20

TACIUK PROCESSOR EXTERNAL SYSTEMS

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D.4 BIODEGRADATION TREATMENT

Soil Slurry Biodegradation

Process Description

There are a number of non in situ biological processes being developed for the treatment of contaminated soils. One non in situ biological process that has proven to be successful in the field is soil slurry biodegradation, also referred to as the liquid/solid contact (or slurry) process.

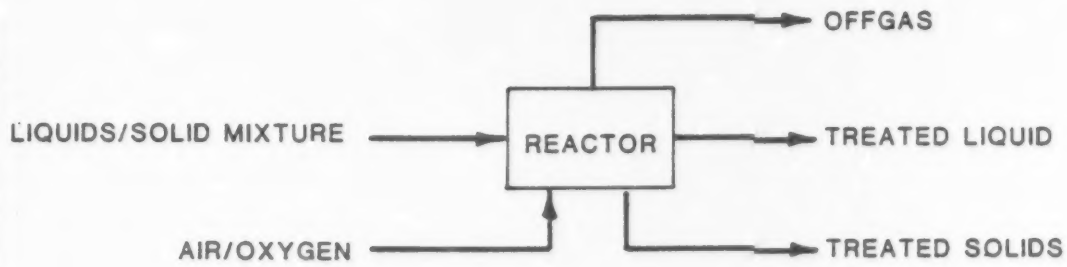
There are two types of soil slurry treatment configurations: single reactor and two-stage system. Although they operate under the same principles, the single reactor system accomplishes treatment in a single reactor or vat and the two-stage system separates the soil slurry mixture step from the biodegradation process (see Figure D-21 for schematics of both systems). Most soil slurry biodegradation projects have used single reactor systems.

For either a single reactor or two-stage system, the first step in the process is the excavation of the contaminated soil. For a single stage reactor, the contaminated soil is then placed into a large vat or tank with water, oxygen, and nutrients. This conglomeration is thoroughly mixed, creating a soil slurry. As the mixing is occurring, biological degradation is taking place. The process creates a leachate and may result in air emissions. Leachate collection/treatment and air monitoring (at a minimum) will be needed. With proper controls and monitoring, contaminant removal efficiencies of 95 - 99 percent have been achieved.

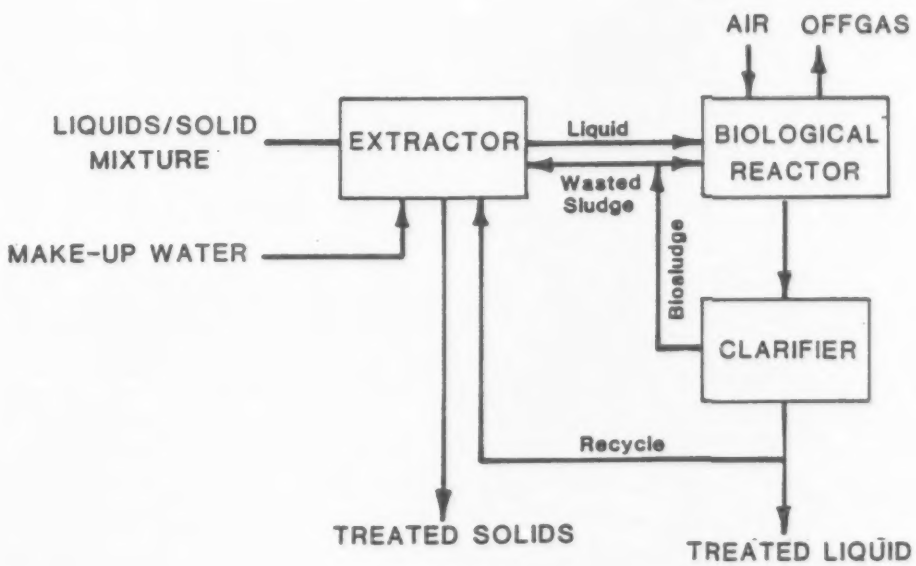
Before beginning any biodegradation process, the characteristics of the soil must be evaluated. Soil slurry degradation requires knowledge of the following parameters to ensure the use of proper ratios of nutrients and oxygen:

1. Existing oxygen content
2. Existing nutrient levels, typically nitrogen and phosphorous
3. Soil alkalinity and acidity
4. Existing bacterial content

SINGLE REACTOR SYSTEM



TWO STAGE SYSTEM



Source: Civil Engineering Magazine
February 1988, p.66
"Biological Treatment of Hazardous Wastes"

Figure D.21

SOIL SLURRY BIODEGRADATION SCHEMATIC

CH2MHILL

Application

Soil slurry biodegradation is an aerobic process and has been used specifically in the wood preserving and treatment industries. Creosote and chlorinated phenols (e.g., pentachlorophenol) are typically the contaminants removed by soil slurry degradation for these industries.

Other organic compounds may be removed from contaminated soil via soil slurry degradation. Soil slurry biodegradation has not proven effective for inorganics.

Landfarming

Process Description

Landspreading is a method of treatment and disposal for low toxicity wastes that promotes further reduction of organic and inorganic constituents by natural processes such as dilution, adsorption, and biodegradation. It should be practised in accordance with local, provincial, and federal land regulations and, if on private property, consistent with lease obligations. Landspread wastes should not contain constituents at concentrations harmful to animals, soil, or vegetation, and should be managed to promote biodegradation and constituent reduction so that groundwater contamination is prevented.

Before landspreading, free oil should be removed from the waste and the waste then spread evenly over the land surface. Generally, the spread waste should be disked into the soil. Where enhancement of biodegradation is desired, nitrogen and other nutrients can be added to the soil before disking, and nitrogen addition/disking can be repeated over the course of time.

Both liquid and solid wastes can be successfully landspread. The two primary concerns are the salt content and hydrocarbon content of the waste. Studies have shown that landspreading that results in waste/soil mixtures with soluble salt levels below about 3000 ppm TDS (approximately 4 mmhos/cm conductivity), an exchangeable sodium percentage less than 15, and a sodium adsorption ratio less than 12 cause no harm to soil, vegetation, surface water, or groundwater. Other studies have shown that landspreading resulting in oil and grease concentrations of up to one percent by weight in the waste/soil mixture is not harmful and will biodegrade readily. As discussed in the preceding paragraph, enhanced techniques such as repetitive disking and nutrient addition may be used to bring the waste-to-soil mixture to these concentrations. The operator should note that site-specific and well-specific conditions can reduce the reliability of the above guidelines.

Wastes that do not meet the above guidelines may be safely landspread when additional management controls are exercised. In such

situations, the operator should ascertain and be prepared to demonstrate prior to disposal (by field history under similar conditions, risk evaluation, laboratory analysis, or field monitoring) that landspreading of the waste will be protective of human health and the environment. Landowner and regulatory agency approval should be obtained under these circumstances.

Landfarming operations usually require controls for surface runoff. Sometimes concern over the potential for migration of contaminants and subsequent groundwater pollution necessitates the installation of a liner before the contaminated soil is spread.

Other common problems associated with landfarming operations are:

1. Over application
2. Soil compaction
3. Contaminant leaching
4. Contamination of surface runoff
5. Undercultivation
6. Malodorous sludges
7. Over or under fertilization

Current regulatory pressure in the United States is making landfarming a more expensive and less desirable treatment alternative. Future regulations may require pretreatment of contaminated materials before they can be landfarmed.

Application

Landfarming is most useful for biodegradable organic wastes such as petroleum sludges and creosote-contaminated soil. In some cases, metals have also been successfully treated by landfarming. However, soils containing contaminants that can interfere with biological processes are not suitable for landfarming.

Certain conditions can make landfarming less desirable as a treatment alternative. These include climates that are cold or have heavy rain. Areas where there would be a significant risk of groundwater pollution also make landfarming less favorable.

In the United States, strict permitting requirements must be met before landfarming is allowed.

Composting

Process Description

Composing involves the storage of highly biodegradable and structurally firm material (e.g., chopped haw, wood chips, etc.) with a small percentage (<10 percent) of biodegradable waste. Composting is enhanced by waste size uniformity. Adequate aeration, optimum temperature, moisture and nutrient contents, and the presence of an appropriate microbial population are necessary to enhance decomposition of organic compounds.

There are three basic types of composting: open windrow systems, static windrow systems, and in-vessel (reactor) systems. The open windrow system consists of stacking the compost into elongated piles. Aeration is accomplished by tearing down and rebuilding the piles. The static windrow system also involves long piles of compost. However, the piles are aerated by a forced air system; i.e., the piles are built on top of a grid of perforated pipes. Finally, the in-vessel system involves placing the compost into an enclosed reactor. Aeration is accomplished by tumbling, stirring, and forced aeration.

In general, compared to in situ biodegradation, composting is relatively insensitive to toxicants. The optimum temperature range for composting is between 10 and 45°C or between 50 and 70°C. It is necessary to collect leachate and runoff water from the composting beds.

TNO of The Netherlands developed a composting-type bioreactor system. It operates under an ambient moisture of 15 to 20 percent and requires no dewatering step after treatment.

Application

Composting has not been widely used but is potentially applicable to both sludges and soils. It is applicable to biodegradable contaminants such as mineral oils, PAHs, and other nonchlorinated hydrocarbons. Microorganisms that secrete acid are used to remove heavy metals. A wide variety of soil types from sand to clay can be treated in a bioreactor.

State of Development

TNO is nearing completion of 2 years of batch-type, laboratory-scale studies. Pilot-scale experiments with a throughput of 10 t/d are currently in preparation. TNO estimates that commercial systems will be batch-operated, have a capacity of 200 or 500 tons, and a treatment time of 10 to 14 days. Either stationary or mobile units can be considered.

D.5 IN SITU TREATMENT

Vitrification

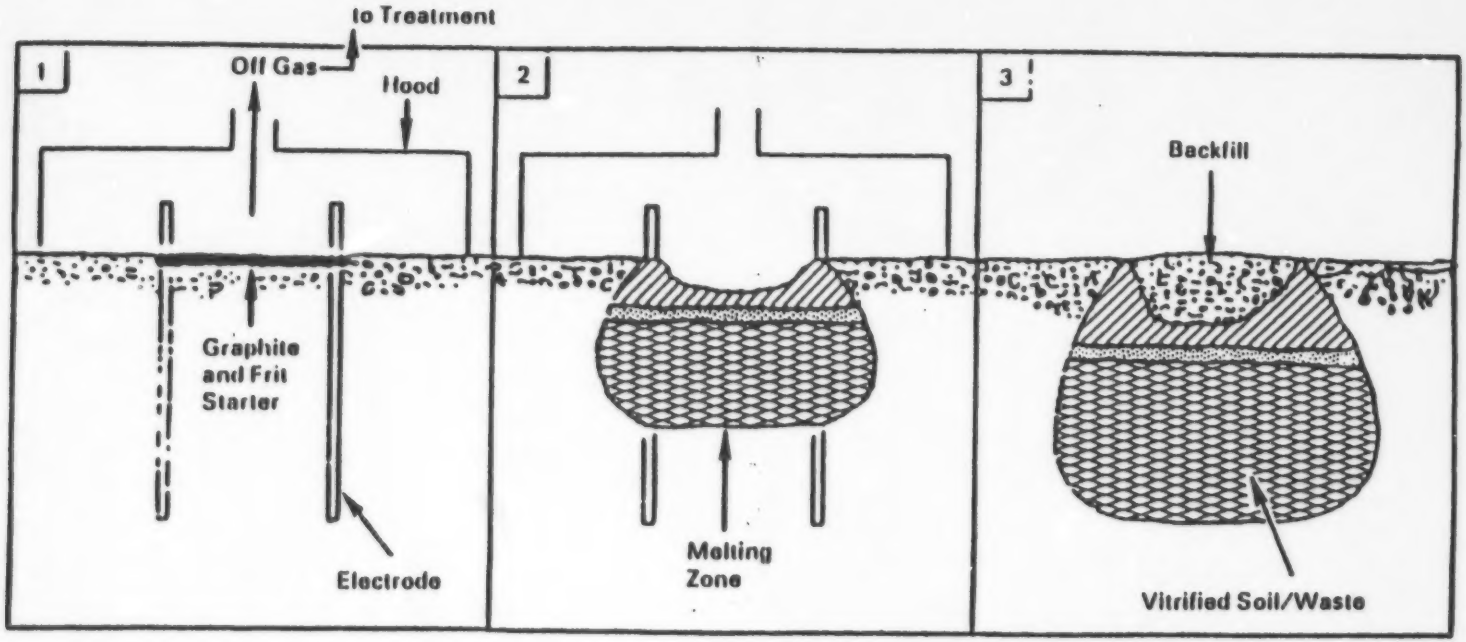
Vitrification is an in situ thermal treatment process (see Figure D-22) which converts contaminated soil or sludge into a chemically inert, stable glass and crystalline product.

Process Description

In the process being developed by Battelle Inc. (currently marketed by its subsidiary, Geosafe Corp.), four molybdenum/graphite electrodes are inserted vertically in the ground in a square array, 3.5 to 5.5 m apart. A mixture of graphite and glass frit is placed in 5-cm by 5-cm trenches on the surface of the soil between the electrodes to form a conductive path. An electric current is passed between the electrodes in the conductive path, creating temperatures high enough to melt the surrounding soil (1600 to 2000°C). The graphite starter path is consumed by oxidation and the current is transferred to the molten soil. The molten zone grows downward, incorporating both soil and soil contaminants and producing a vitreous mass. Up to 5 yd^3 of soil can be vitrified per hour following startup. Power consumption for a typical melt is approximately 1 kWh/kg of soil vitrified. The thermal gradient at the edge of the melt goes from 1600 to 2000°C in the molten zone to 100°C approximately 30 cm from the melt.

The electrical field around the electrodes causes convective currents in the molten zone which distribute nonvolatile contaminants uniformly within the zone. Organic contaminants are reported to be completely pyrolyzed in the high-temperature anoxic zone. Pyrolysis byproducts migrate to the surface of the vitrified zone where they combust in the presence of oxygen.

When the power to the system is turned off, the molten zone begins to cool and a block of glass-like crystalline material resembling obsidian is produced. Soil subsidence will result in a 15 percent to 20 percent volume reduction of soil from the natural grade in the molten zone. The subsided area can be backfilled with clean material in about 2 weeks. Completed cooling to ambient temperatures may take up to a year.



Source: Battelle Pacific Northeast Laboratories

Figure D.22

IN SITU VITRIFICATION PROCESS SCHEMATIC

The length of an average melt is reported to be from between 4 to 7 days, depending on the volumetric quantity and the extent of the molten zone. For adjacent melts, it takes approximately 16 hours to move the hood and off-gas treatment system from the completed area to the next molten zone.

Off-gases are collected by a hood placed over the processing zone and routed to an off-gas treatment system. The off-gas treatment system can be customized to treat specific site contaminants and can contain scrubbers, adsorbers, and filters.

Byproducts include stable/immobile molten glass and volatile organic combustion products that will need to be collected and treated.

Applications

The process was developed for the treatment of soils contaminated with transuranic radioactive wastes, but it is also reported to be applicable for the treatment of heavy metals, PCBs, dioxin, and organic-solvent contaminated wastes (MEK, carbon tetrachloride, and TCE). The system can reportedly handle wastes with up to 7 percent combustible material by weight and void volumes of one percent.

In situ vitrification is an emerging technology that, as of 1988 March, has not been used for full-scale remediation of any contaminated sites. The system is currently undergoing design of the vitrification equipment and hood. At this point, there are major technical design details to be worked out before it is a viable portable treatment system.

Development and construction of a full-scale portable system for remediation of contaminated sites is scheduled to be completed by 1988 September. A large size (18.2 m x 18.2 m) off-gas hood system is currently at the conceptual design stage.

Radio Frequency (RF)

Process Description

A system of electrodes implanted in the soil directing radio frequency (RF) energy into the ground will heat the soil to a predetermined temperature and volatilize trapped hydrocarbons. The technique relies on molecular agitation, much like a microwave, to heat the soil. The vaporized contaminants and soil moisture are vented to a surface vapour barrier, then condensed for disposal or incineration onsite.

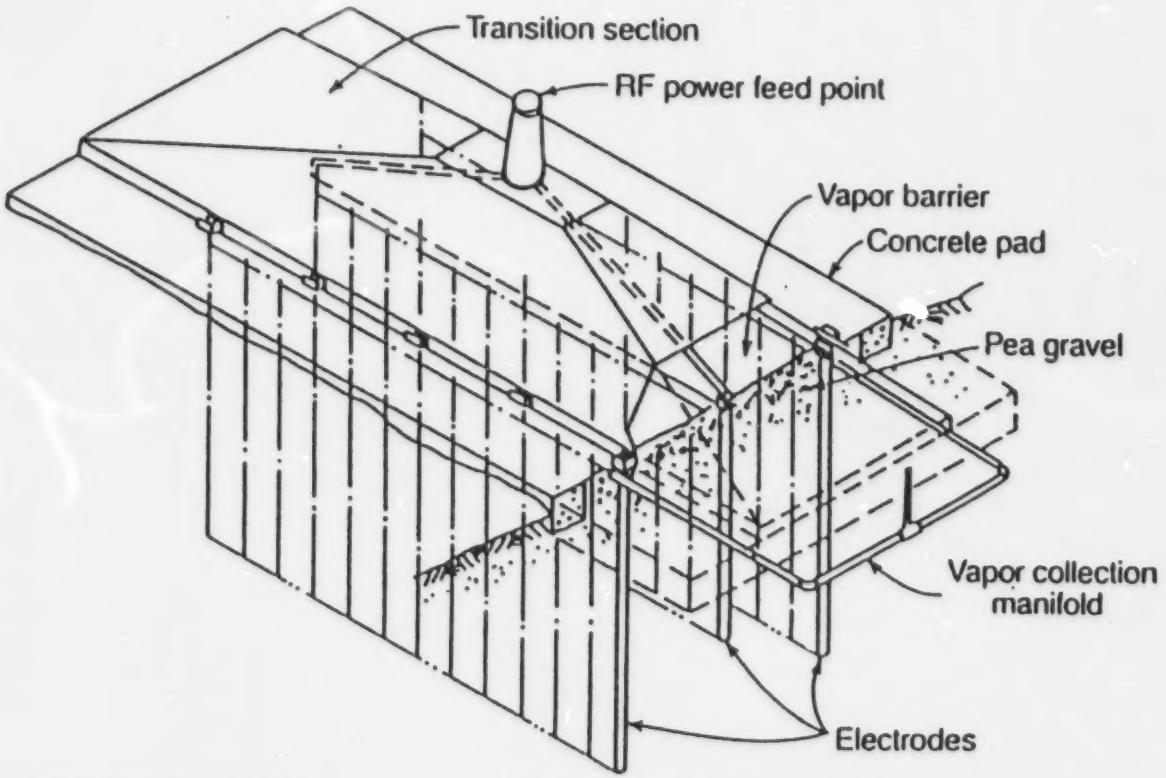
A modified radio transmitter applies electromagnetic energy in the RF band. The dielectric properties of the soil matrix and the size of the area requiring treatment determine the frequency used for the operation.

Figure D-23 shows a schematic of a typical in situ electrode configuration.

Applications

RF treatment has been pilot tested to a depth of 4 m below the surface in a soil with an average petroleum concentration of 0.4 percent.

Reduction of contaminants and soil moisture to greater than 90 percent was achieved in the heated zone, and to approximately 70 percent was obtained in areas beyond the test zone parameter. This system was developed by Harsh Dev of the IIT Research Institute, Chicago, Illinois.



Source: Civil Engineering Magazine, August 1988, p.43

Figure D.23

RADIO FREQUENCY SYSTEM SCHEMATIC

Solidification/Fixation

Process Description

Fixation is the chemical or physical technology used to detoxify, immobilize, insolubilize, or render a waste component less hazardous or less capable of releasing itself into the environment.

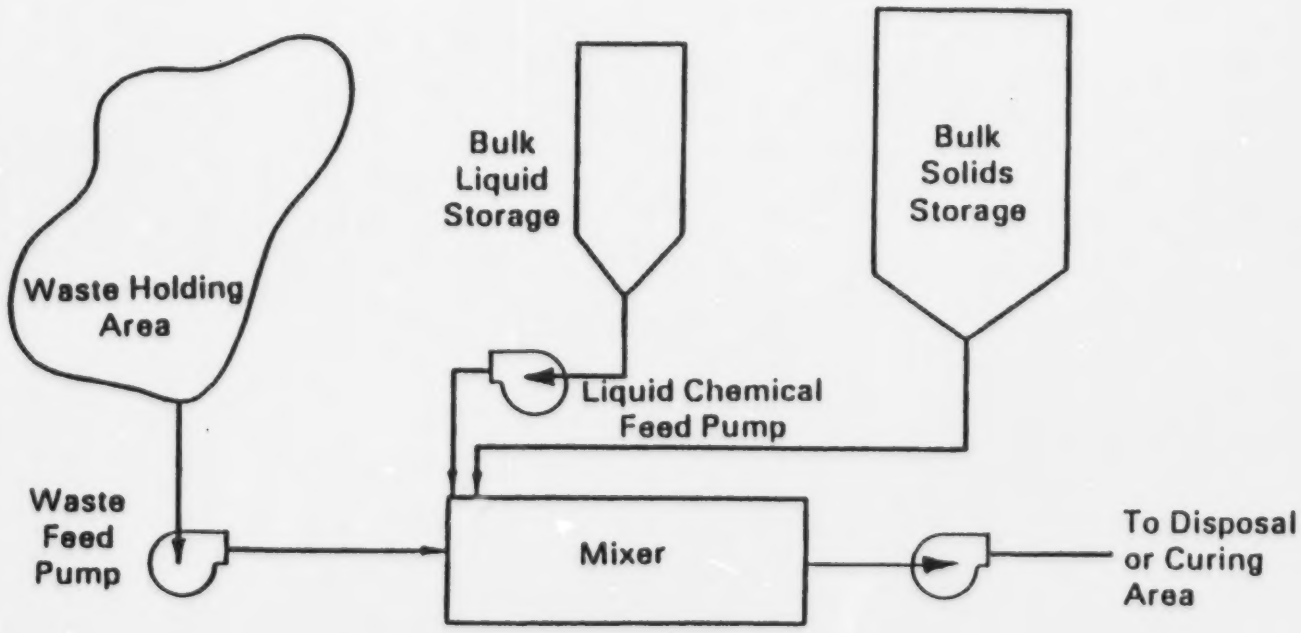
Examples of fixation techniques are immobilization, which captures the hazardous components within the contaminated soil mass, and degradation, which chemically converts the contaminants into an innocuous or less toxic compound. The three major classes of immobilization techniques are adsorption, ion exchange, and precipitation. Chemical oxidation, reduction, and polymerization are three types of degradation processes.

In situ fixation is designed to accomplish one or more of the following objectives:

1. Decrease the surface area from which transfer of contained pollutants can occur.
2. Limit solubility of, or detoxify a hazardous constituent in a waste.
3. Contain hazardous constituents in a bonded matrix to prevent leaching to surrounding soils or groundwater.

Solidification is the process of solidifying or transforming the residue into a physical form that is more suitable for storage, transportation, landfill, or reuse. This process, which can occur without chemical fixation, goes one step beyond fixation to result in a monolithic block of treated waste with high structural integrity. Wastes can be solidified with cement, lime, organic polymers, asphalt, and a variety of proprietary products. Figure D-24 shows a solidification/fixation process schematic.

Once a hazardous waste has been fixated or solidified, it is still considered a hazardous waste. This process just contains the waste to eliminate the threat to human health and the environment. In some situations, encapsulation, surface sealing, or capping may be desirable to use in conjunction with in situ fixation to prevent moisture infiltration or disturbance of the fixed material.



Source: U.S. Environmental Protection Agency

Figure D.24

SOLIDIFICATION/FIXATION PROCESS SCHEMATIC

CH2MHILL

Encapsulation is a physical process by which a solidification agent surrounds waste particles and binds them into a mass. One proprietary process involves the placement of a ¼-inch thick, high-density polyethylene jacket around a block of solidified waste.

The equipment requirement for in situ fixation will vary from site to site and according to waste type. However, in general, treatment of the soil will require chemical storage, earth moving equipment, mixing systems, and chemical injection equipment.

The cost for implementing a fixation treatment process includes the cost of the chemicals, equipment rental, mobilization and demobilization, and labour. In general, at sites where the waste and geography are amenable to the treatment, and depending on the fixation agent used, in situ fixation has been found to be one of the most economical treatment alternatives available. Treatment costs range from $50 to $140 per tonne, depending on site and waste characteristics.

Application

Fixation processes are normally applied to wastes containing appreciable amounts of toxic heavy metals and/or inorganic salts. Wastes containing more than 10 to 20 percent organic constituents are not generally suitable for fixation.

Applicability of these techniques is affected by both waste and site characteristics. Some waste constituents interfere with the solidification process. Therefore, the wastes must undergo a thorough analytical characterization and stabilization evaluation to ensure compatibility with this treatment option. The site geology and depth of the contamination are also important considerations. While this technology offers promise in decreased leaching, no data are available on the long-term stability and integrity of solidification matrices.

State-of-the-art fixation methods are rapidly advancing as manufacturers develop new equipment and fixation agents.

At present, cement and lime-based processes capable of solidifying a wide range of materials are readily available. The thermoplastic and organic polymer processes are often developed on a waste-specific basis and involve the use of proprietary chemicals and procedures. Some of the current manufacturers/suppliers are listed below.

1. Chemfix Technologies Inc. (CTI)
2. International Waste Technologies, Wichita, Kansas
3. Japan National Railways & Sanwa Kizai Co., Ltd.
4. Professional Solidification International, Midland, Texas

Biological Treatment

Process Description

There are a variety of biological processes available for in situ treatment of contaminated soils. The most notable are enhanced biological degradation, enhanced detoxification, enhanced mineralization, and bacterial augmentation. At the forefront of bioreclamation (biological treatment for contaminated soils) is enhanced biological degradation (also termed biodegradation).

Biological degradation refers to the use of microorganisms, primarily bacteria, actinomycetes, and fungi, for the metabolism of organic compounds and some inorganic compounds leading to the decomposition, detoxification, and mineralization of the parent compound(s) in the soil. For most situations, existing indigenous aerobic bacteria or introduced cultural strains of aerobic bacteria are used for treatment of the contaminated soil.

Prior to beginning an in situ biodegradation process, the characteristics of the soil must be evaluated. Enhancement entails altering the soil surface and/or subsurface environment with respect to one or more of the following parameters:

1. Oxygen content (electron acceptors)
2. Nutrient levels (typically nitrogen and phosphorus)
3. Moisture content (approximately 8 - 15 percent, or greater than -15 bars)
4. Soil alkalinity and acidity (pe + pH) between 17.5 - 2.7
5. Temperature (optimally between 10 - 15°C, but conceivably between 10 - 40°C)

Treatments applied to the soil to enhance contaminant biodegradation must not alter the physical environment to an extent that other environmental concerns are generated.

The degree of contaminant biodegradation is often limited by oxygen availability. Oxygen availability can be increased in surface bioreclamation by promoting the diffusion of oxygen through soil pores.

Many soils contain most of the inorganic nutrients required for microbial metabolism. Nitrogen and phosphorous often are the

nutrients that limit the process. Microbial acitivity can sometimes be dramatically increased by application of these nutrients. Potassium supplements are also sometimes required.

While many microbes can persist for extended periods in the absence of unbound water, the presence of free water is required for metabolism. Microbial activity generally increases with increasing soil moisture content; however, saturation of soils can lead to anoxic conditions and deactivation of the microorganisms.

Bacterial and other microorganisms' activities are optimum in specific ranges of temperature (10 - 40°C) which vary with type. Therefore, in many parts of the world, enhanced biodegradation is a seasonal process.

The addition of organic nutrients and/or the addition of specific cometabolites, inoculation with exogenous microorganisms, or addition of cell-free enzymes could also potentially increase the rate and extent of contaminant biodegradation.

Figure D-25 shows a conceptual diagram for the in situ biodegradation process.

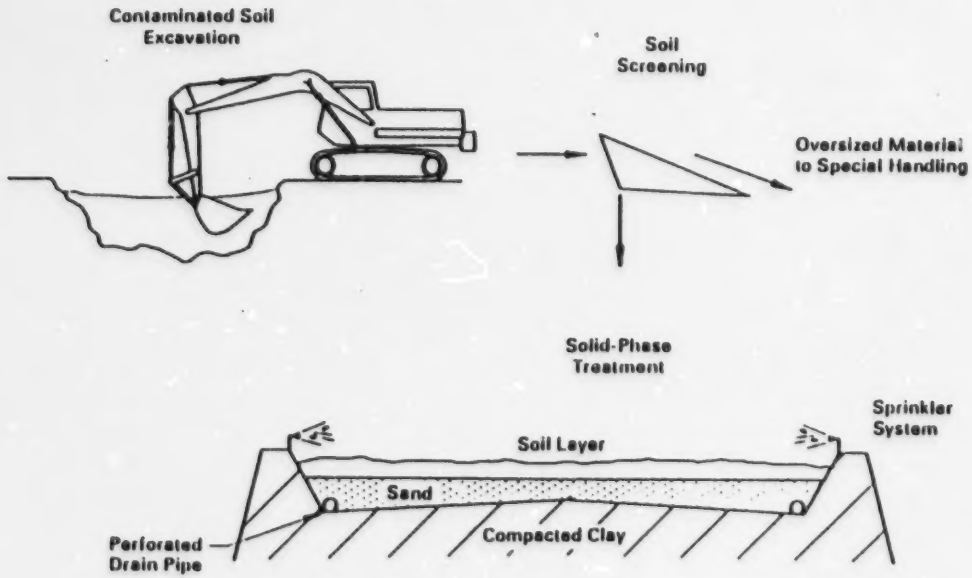
Application

Enhanced biodegradation is typically an aerobic process and has been used specifically in the petroleum, wood preserving, and pesticide industries. Contaminants that are potential candidates for biodegradation include most organic compounds and organic/inorganic complexes.

In situ enhanced (aerobic) biodegradation is often used in conjunction with groundwater cleanup. A groundwater pumping and reinjection system is often used to circulate nutrients and oxygen through the contaminated aquifer and the associated contaminated soils.

Enhanced biodegradation works particularly well with organic compounds, including:

1. Pesticides (e.g., DDT, DDE, DDD, dieldrin, lindane, and mirex)
2. Halogenated aliphatics
3. Biodegradable nonhalogenated organics (e.g., gasoline, diesel fuel)



Source: Ecova Corp.

Figure D.25

IN SITU BIODEGRADATION

4. Hydrocarbon solvents (e.g., benzene, toluene, xylene)
5. Monocyclic and polycyclic aromatic compounds
6. Phenolic compounds
7. Halogenated ethers and phthlate esters
8. Alcohols, ketones, and glycols
9. Polychlorinated biphenyls (PCBs)

Reagent application and incorporation are more easily accomplished with agricultural implements than by the subsurface injection/withdrawal approach, making surface and shallow subsurface contamination more amenable to in situ treatment that deeper contamination.

Equipment

In situ biodegradation requires incorporation of the treatment reagent(s) into the contaminated medium. The means by which this is done is largely dependent on the depth of contamination. Different equipment is mandated for contaminants located only in the shallow subsurface zone (approximately the first metre of soil depth) than for deeper contaminants.

Conventional agricultural techniques can be used in cases where the contamination is in the shallow subsurface zone. Plows, harrows, discs, sprayers, spreaders, and injectors are examples of conventional agricultural implements that can be used to achieve application and mixing to surface or shallow subsurface soils or other contaminated materials. For deeper contamination or for water-saturated surface soils, draining of the soil may be necessary.

Experience

Enhanced biodegradation techniques have been used successfully in the past. The most developed enhanced biodegradation techniques are those relying on aerobic processes. Historically, most contaminant biodegradation research has focused on aerobic processes, with the result that they are much better understood than anaerobic processes. Recently, more research on anaerobic biodegradation of organic contaminants has been conducted. Several field studies on biodegradation of contaminants have been conducted, including studies

under anoxic conditions. The results of these studies show that anaerobic processes may be an important bioreclamation technique. For the present, however, it can be generalized that aerobic biodegradation techniques are more developed than anaerobic techniques and that aerobic biodegradation is more rapid and complete than anaerobic biodegradation.

Biodegradation of hazardous waste-contaminated soils using the addition of cometabolites, the application of cell-free enzymes, or inoculation with mutant microbial strains is still at the laboratory stage of development.

D.6 OTHER TREATMENT/DISPOSAL PROCESSES

Industrial Landfill

In Alberta, industrial landfills are divided into three classes according to the type of waste that may be accepted for disposal, and associated engineering features which supplement hydrogeologic conditions to prevent groundwater and surface water contamination.

A Class I industrial landfill is the most sophisticated type. It cannot accept hazardous wastes that are prohibited by regulation from landfill disposal.

A Class II industrial landfill requires fewer engineering considerations than a Class I landfill, but cannot accept any liquid hazardous waste or hazardous waste containing free liquids, as well as the other hazardous wastes prohibited by regulation from landfill disposal.

A Class III industrial landfill is restricted to inert solid wastes.

For disposing of the types of wastes considered in this study, a Class I industrial landfill would be required and would have the following engineering features:

1. Two liners of which at least one is a synthetic liner
2. A leachate collection and removal system
3. A leak detection system between the two liners
4. Surface run-on and run-off control systems
5. A suitable gas interception and venting system where gas generation is expected
6. A groundwater monitoring system consisting of observation wells located in areas hydraulically upgradient (background quality) and downgradient of the facility

Hot Mix Asphalt (HMA)

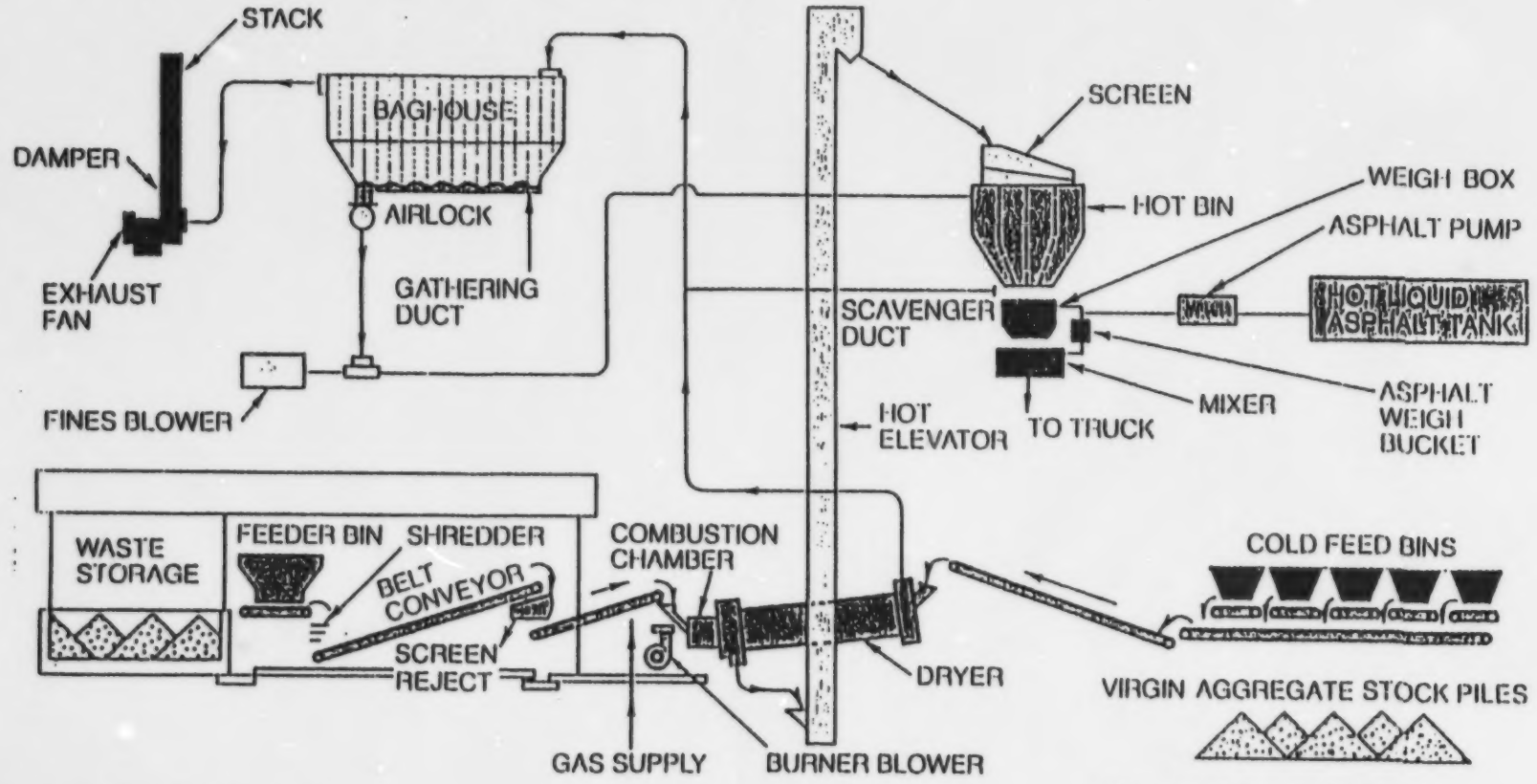
Process Description

Ordinarily, HMA aggregate moves from cold feed bins via belt feeders to a collecting conveyor and enters a dryer at the end opposite the burner. After the water evaporates and the aggregate is heated to about 177°C, it leaves the dryer and is carried via a bucket elevator to a set of screens and separated into hot bins. It is subsequently made into HMA.

George Brox, Inc. of Dracut, Massachusetts, developed a process using 95 percent virgin to 5 percent contaminated soil to produce a good quality HMA. The treatment plant starts with a concrete storage area holding the contaminated soil. The soil is loaded into a bin and fed in proportion to virgin aggregate into the process on a belt feeder. The soil passes over a scalping screen to remove large particles and then into a rotating ceramic cylinder. This cylinder is 1.5 m in diameter and 1.5 m long and is located between the burner and the dryer (see Figure D-26). It rotates counter to the rotation of the dryer and can be adjusted from 0 to 6 rpm. Soil is held in it for at least one minute. Fired by the burner, the cylinder acts as a combustion chamber. Water and hydrocarbon in the soil are flashed off by the 1100°C flame and the soil leaves the cylinder at approximately 450°C. The vaporized hydrocarbon is incinerated and destroyed. Exposure to the flame is calculated at 1.2 s, based on a 5-m flame length and a gas velocity of 4 m/s. A recent test burn using toluene and xylene in sand as simulated contaminated soil resulted in 99.25 percent destruction.

Application

Not all soils are suitable for recycling into HMA. High clay content reduces the asphalt's overall strength. The -200 mesh material in the soil is limited to 20 percent. Oversize material larger than 20-mm diameter is rejected. So far, the plant is allowed to process soil contaminated with virgin oil, kerosene, or gasoline with no more than 3 percent oil content.



Source: Civil Engineering Magazine, December, 1988 p.72

Source: Aztec Industries, Inc.

Figure D.26

HOT-MIX ASPHALT SCHEMATIC

CHEMHILL

Aglofloat Process

Process Description

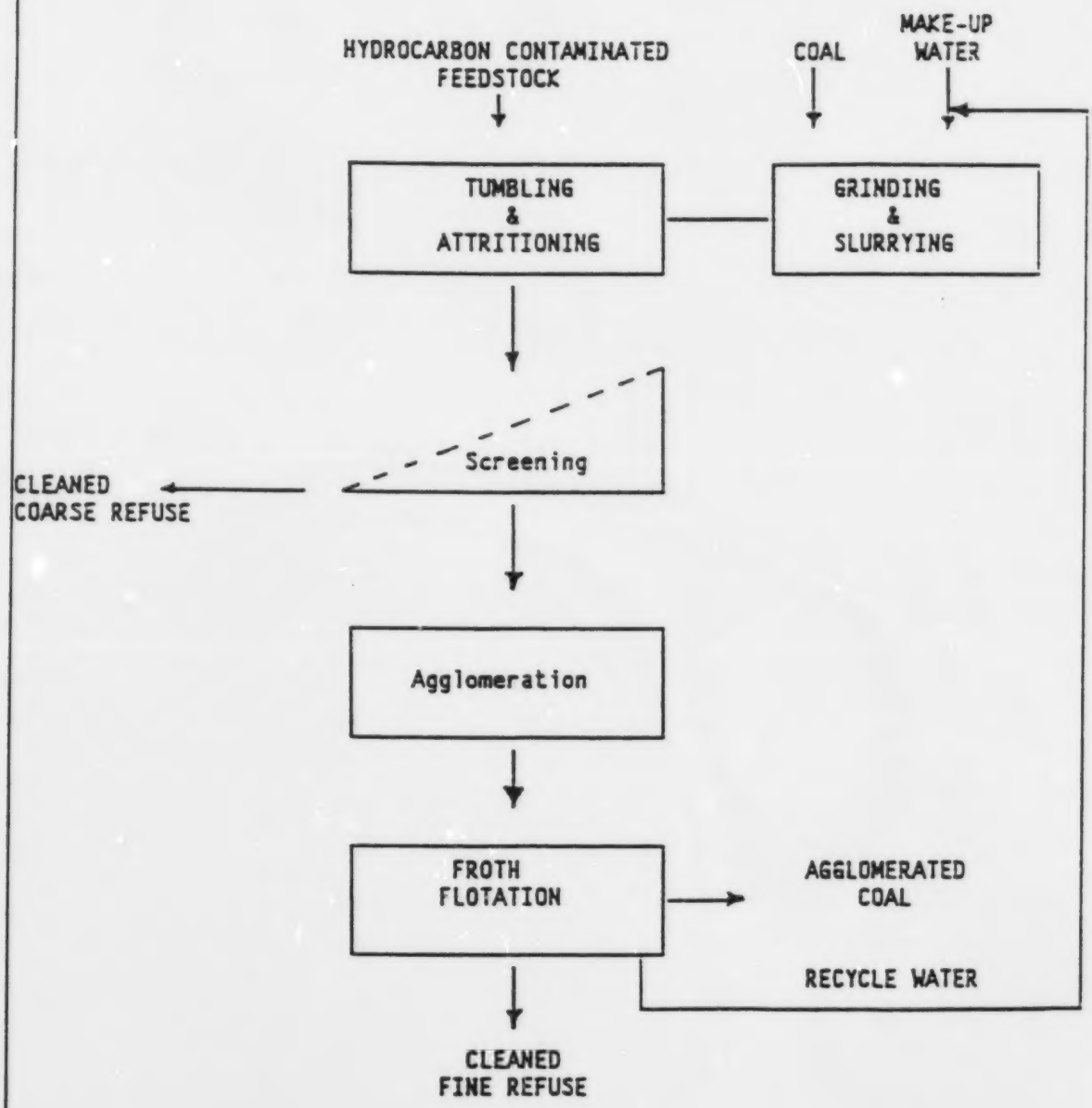
Alberta Research Council (ARC), under a program sponsored by a Canadian-U.S. consortium, developed the process. The 6-t/d, integrated testing facility is designed to study various unit operations involved in selective agglomeration of coal fines by hydrocarbon binders in the aqueous phase.

In the process, coal from the mine is crushed and fed to the mill. Water is added and further grinding takes place. Hydrocarbon-contaminated material is added to the slurry. The slurry is fed to the mixer to form agglomerates. Clay and sand are left in the water slurry. The coal/oil agglomerates are separated from the sand by froth-flotation, where air is bubbled through the slurry to push the agglomerates to the surface. The agglomerates skimmed off from the flotation tanks are washed on vibrating screens to remove fine clay. The wastewater from the froth flotation and screen washing is treated in settling tanks to remove solid refuse and then recycled back to the process. A schematic flow diagram is shown in Figure D-27.

Application

The technology can be applied for:

1. Benefication of subbituminous coals with the use of high molecular weight hydrocarbons as a binder
2. Desulphurization of bituminous coals
3. Recovery of hydrocarbons from oil wastes, tar refuse, and contaminated soil



Source: Alberta Research Council

Figure D.27

AGLOFLOAT PROCESS SCHEMATIC

Colt Treater

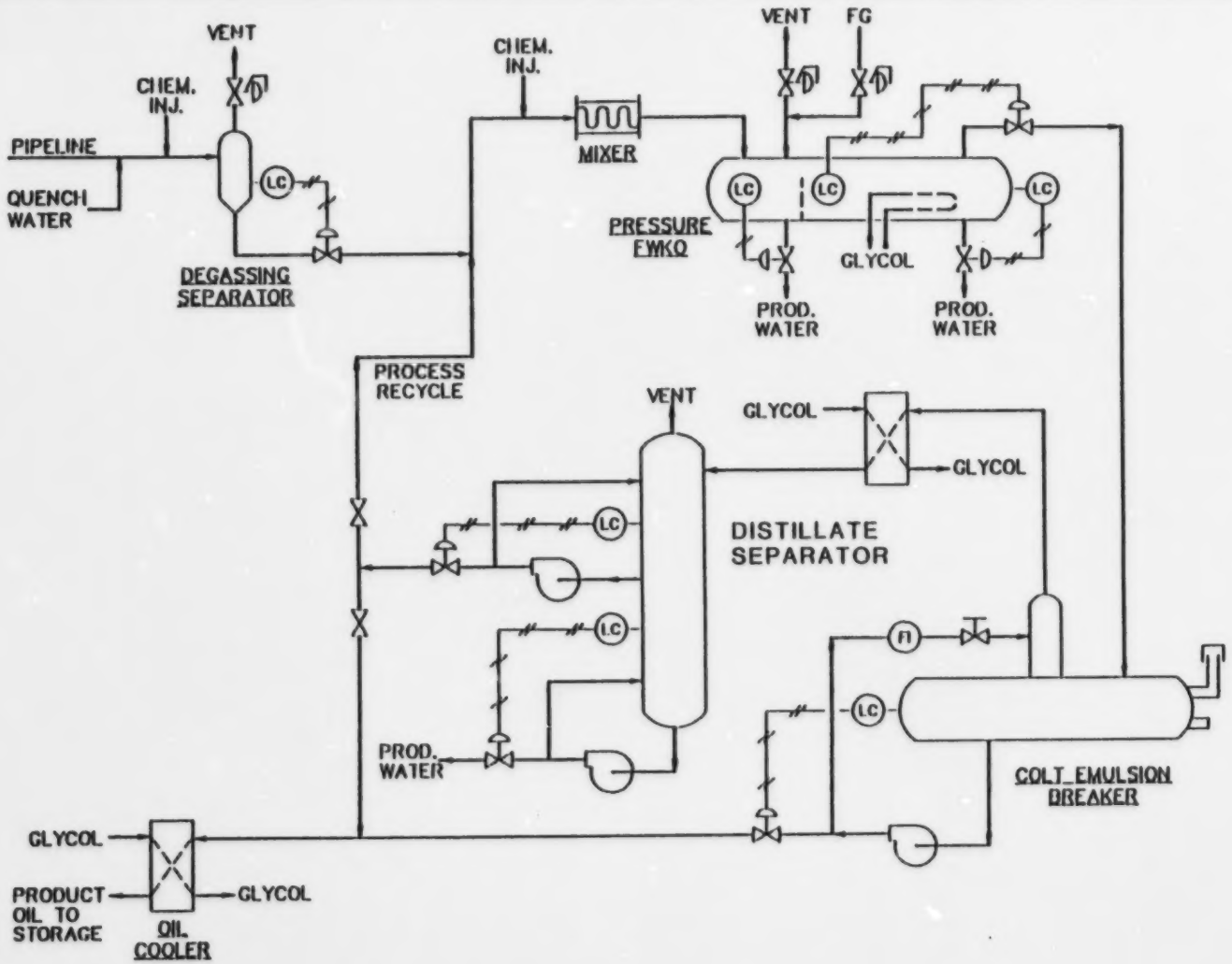
The Colt Treater evolved as a direct result of the introduction of enhanced recovery methods to produce heavy oil (9 - 12 API). All of the enhanced recovery techniques, including steam drive, cyclic steamflood, fireflood, oxygen flood, and steam/carbon dioxide flood, produced oil emulsions of varying types, thus resulting in treating facilities and equipment operating with varying degrees of success. Typically, an oilfield treater would produce an interface pad of emulsion that would have to be periodically drawn off and recycled, batch treated, or in some cases stored indefinitely as untreatable slop oil. The use of the Colt treater is one way of eliminating or reducing the volume of slop oil.

Process Description

The Colt Treater is a distillation system operating at atmospheric pressure and at temperatures of 125 - 130°C. Figure D-28. shows how a Colt treater would fit into a typical cyclic steamflood process. Wet oil is co-mingled with the hot recycle stream and fed into the treater vessel. The water in emulsion is vaporized along with the lighter hydrocarbons present. Dry oil is pumped to storage or back to the vessel to provide continuous desanding and reflux to the distillation column. Distillate vapours, water, and hydrocarbon exit the treater and are recondensed. The condensed fluid flows to a three-phase separator where it is allowed to separate to water, condensate, and noncondensable vapours. The water is pumped to disposal. The noncondensables are vented. The condensate hydrocarbon liquid is recycled back to the sales stream, into the free water knockout inlet, or sold as a product.

Application

The Colt Treater is applicable for treating treater and separator interface material that consists of mainly hydrocarbon, aphaltene, and wax.



Source: Cord Projects Ltd.

Figure D.28

TYPICAL APPLICATION OF THE COLT TREATER FOR STEAM CYCLIC OIL PRODUCTION

CH2MHILL

Oleophilic Sieve Process

Process Description

The oleophilic sieve process is based on the theory that when a mixture of oil phase and aqueous phase is passed through a sieve made from oleophilic materials, the aqueous phase and the hydrophilic solids contained in that phase will pass through the sieve apertures, but the oil will adhere to the sieve surface on contact.

Figure D-29 presents a schematic of a one-stage treatment process. The sieve is a moving conveyor which runs fast enough to prevent blinding of the sieve by the adhering oil phase while the aqueous phase passes through the sieve.

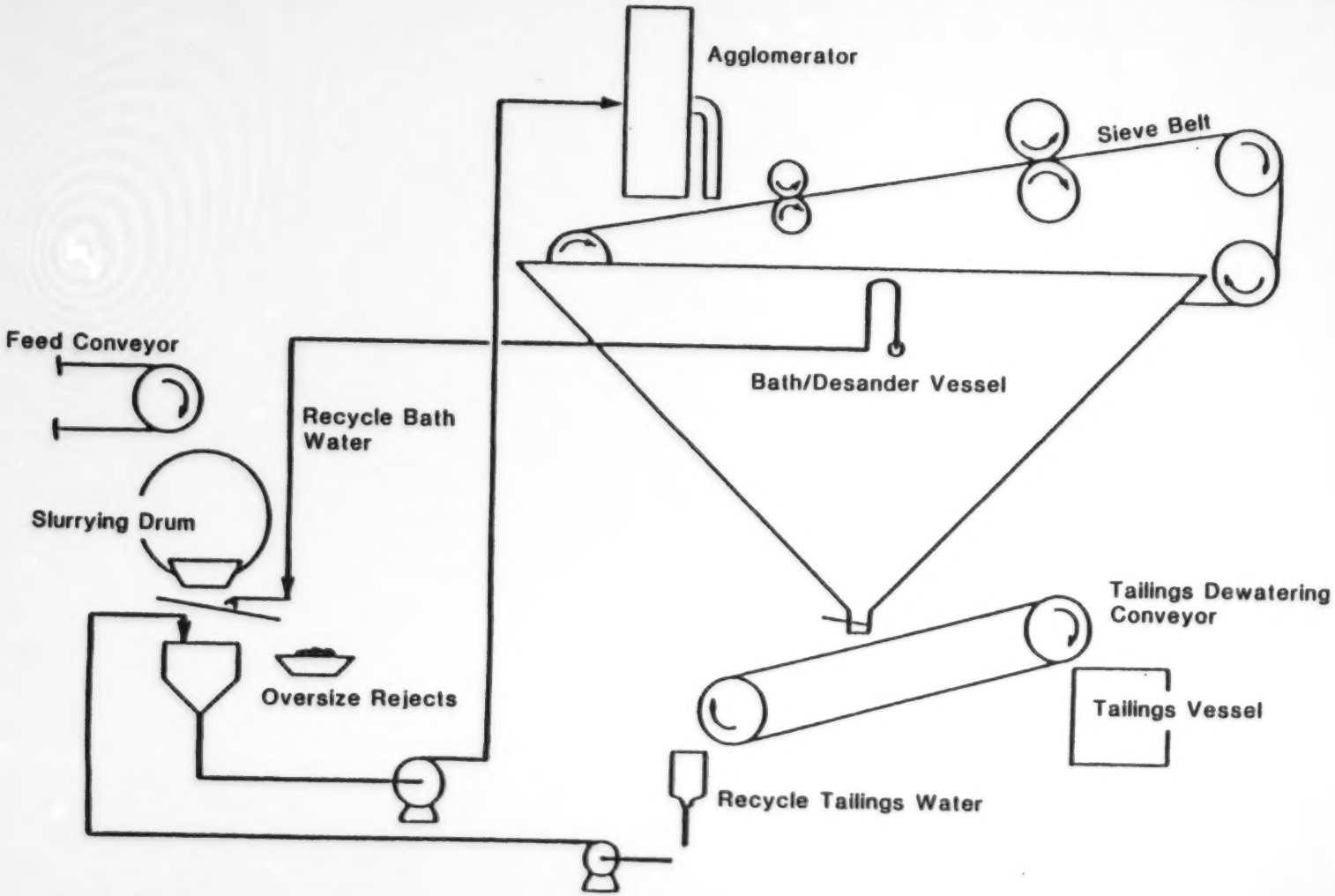
The oleophilic sieve is an aperatured oleophilic endless process belt supported by conveyor rollers to form a straight and approximately horizontal top flight and a bottom flight that hangs down in the form of a catenary in the mixture it is separating. The bottom flight collects the oil phase from the mixture with the aid of buoyancy and oleophilic adhesion as the belt emerges out of the mixture. The captured oil is conveyed to the top flight where, with the aid of gravity and heat to reduce the viscosity, it falls into a receptacle under the top flight.

Application

The oleophilic sieve process has been used to recover bitumen from a variety of sources, including mined oil sand slurries, tailing, middlings, and pond sludges under pilot testing. Recovery of heavy minerals and oil from contaminated land sites has also been processed.

As of 1988 January, the oleophilic sieve technology is undergoing patenting, and thus no commercial facility processing heavy oil production wastes is operating.

The largest shop-fabricated unit is capable of operating 900 m^3/h of sludge, and smaller versions can be manufactured for mobile applications.



Source: Oleophilic Sieve

Figure D.29

OLEOPHILIC SIEVE PROCESS FLOW DIAGRAM

The performance of the process is dependent upon the temperature and viscosity of the oil to be recovered. Generally, the colder the separating mixture, the better, and the more viscous the captured oil phase, the better. Wastes must be water-wetted or suspended in water before feeding the process. Further downstream treatment to process the separated contaminants before landfill disposal is required.

Gravity Separation

Process Description

Gravity separation processes do not destroy contaminants. They change the hazardous constituents to a more convenient and more easily handled form through equalization, concentration, and/or phase change. These processes often separate the waste into two streams, one dilute and the other a highly concentrated volume of hazardous material that must be placed in a landfill or undergo additional treatment. Many gravity separation processes are consequently used in combination with other treatment processes.

The process used for oil/water separation depends primarily on the state of the oil phase. The terms used to describe the oil phase are defined in the following paragraphs.

Free oil is oil that is in large enough particles or droplets to float (or sink) within a few hours in a gravity separation vessel such as a skim tank or API separator under quiescent and isothermal conditions.

Suspended oil includes oil which can be caught on a 0.5-micron membrane filter. The definition includes finer oil that separates in advanced design separation vessels such as induced gas flotation (IGF), dissolved air flotation (DAF), corrugated plate interceptors (CPI), or coalescing filters.

Dissolved oil is oil measured from a filtered sample by extraction with a low polarity solvent such as methylene chloride.

Emulsified oil is all oil except free oil.

Separation of free oil can be accomplished by a simple gravity separator. This is a chamber arranged so that floating matter rises and is removed from the surface while the water flows out continuously under partitions. Gravity separators are equally effective in removing both greases and free oils.

Dissolved oil requires chemical treatment for separation and cannot be separated by physical treatment alone, such as filtration or flotation methods. Dissolved oil can also be removed by carbon adsorption.

Emulsified oil requires treatment to break the oil/water emulsion prior to gravity separation. After the oil is freed by one of these methods, it is separated by the simple gravity method. Emulsions may be broken by chemical or thermal methods, usually by lowering the pH to 2 or 3, heating to 160°F or above, and possibly using emulsion breaking polymers or other chemicals.

Sedimentation is a physical process that removes suspended solids from a liquid by gravity. The wastewater is fed into a tank or lagoon where it loses velocity and the suspended solids are allowed to settle out. Sedimentation is sometimes preceded by chemical precipitation and/or by coagulation and flocculation.

The sedimentation process is commonly carried out in settling ponds which can range from one to several hundred acres in size, depending on the flowrate and nature of the solids, or clarifiers which can be circular or rectangular. Sedimentation performance is related to the surface loading or overflow rate.

Application

Oil separation is used throughout industry to recover oil for use as a fuel supplement, for recycle, or to reduce the concentration of oils that have deleterious effects on subsequent treatment or receiving waters.

Sedimentation is a low-cost process used to separate suspended solids from liquid streams. Common applications include removal of chemically precipitated solids, such as metal hydroxides, or removal of biomass generated by biological treatment.

Appendix E
VENDOR INFORMATION

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TECHNOLOGY	VENDOR/DEVELOPER	CONTACT
Rotary Kiln Incineration	Westinghouse Environmental Services Madison, Pennsylvania	William H. Reed 412/722-5303
	Environmental Systems Little Rock, Illinois	Don Richter 501/223-4100
	John Zinc Co. Tulsa, Oklahoma	Ted Willis 908/747-1371
Infrared Thermal Destruction	Westinghouse Environmental Services Madison, Pennsylvania	William H. Reed 412/722-5303
Molten Salt	Rockwell International Canoga Park, California	
	John Zinc Co. Tulsa, Oklahoma	Ted Willis 908/747-1371
Fluidized Bed	Ogden Environmental Services San Diego, California	Harold Diot 619/455-2383
Electric Pyrolyzer	Westinghouse Environmental Services Madison, Pennsylvania	William H. Reed 412/722-5303
Taciuk Processor	UMATAC Industrial Processes Calgary, Alberta	R.M. (Bob) Ritcey 403/279-8080
RTR/GULF Sludge Conditioning	RTR Oil Sands (Alberta) Ltd. Calgary, Alberta	Carlos J. Valdes 403/233-4962
Oleophilic Sieve	Oleophilic Sieve Development of Canada Ltd. Edmonton, Alberta	Jan Kruyer 403/469-1240
Vitrification	Geosafe Corp. Kirkland, Washington	James E. Hansen 206/822-4000
Radio Frequency Heating	IIT Research Institute Chicago, Illinois	Harsh Dev 302/567-4000
Solidification/ Fixation	Professional Solidification International Midland, Texas	Fred Holmes 915/682-8597
Soil Slurry Biodegradation	Bogart Environmental Services Inc. 263 Mt. Juliet Road Mt. Juliet, Tennessee 37122	Jim League 615/754-2847

Appendix E
(Concluded)

TECHNOLOGY	VENDOR/DEVELOPER	CONTACT
Critical Fluid Solvent Extraction	CF Systems Corporation 140 Second Avenue Waltham, MA 02154-1100	Tom Cody 617/890-1200
Hot Toluene Solvent Extraction	Tricil Limited 89 Queensway West Mississauga, Ontario L5B 2V2	Jim Suddaby 416/270-8280
B.E.S.T. Solvent Extractibn	Resources Conservation Company 3006 Northup Way Bellevue, Washington 98004-1407	Paul McGough 206/828-2400
MTA Soil Washing	MTA Remedial Resources, Inc. 1511 Washington Avenue Golden, Colorado 80401	Rich Hogan 303/279-4255
In Situ Biological Treatment	ECOVA Corporation 3820 - 159th Avenue N.E. Redmond, Washington 98052	Al Bourquin 206/883-1900
Hot-Mix Asphalt Process	George Brox, Inc. 1417 Methuen Street Dracut, Massachusetts 01826	Bob Rio 508/454-9105
Aglofloat Process	Alberta Research Council Coal and Hydrocarbon Processing Department 1 Oil Patch Drive Devon, Alberta T0C 1E0	Les Ignasiak 403/987-8111
Colt Treater	Cord Projects Ltd. 400 - 10210 Southport Road S.W. Calgary, Alberta T2W 4X9	Bryan Hamilton 403/253-9305
BP Oil Solvent Laskowski Extraction	B.P. Oil Company 200 Public Square Cleveland, Ohio 44114-2375	John Laskowski 216/586-3968
USEPA Soil Washer	U.S. Environmental Protection Agency, Risk Reduction Engineering Laboratory Superfund Technology Demonstration Division Woodbridge Avenue Edison, New Jersey 08837	Richard Traver 201/321-6677